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APPROXIMATE INTERVAL ESTIMATION
METHODS FOR THE RELIABILITY OF
SYSTEMS USING DISCRETE
COMPONENT DATA

by

Edmundo F. Bellini

September 1990

Thesis Advisor

W. Max Woods

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Approximate Interval Estimation
Methods for the Reliability of
Systems Using Discrete
Component Data

by

Edmundo F. Bellini
Lieutenant, United States Navy
B.S., United States Air Force Academy, 1976

Submitted in partial fulfillment of the
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Author:

Edmundo F. Bellini

Edmundo F. Bellini

Approved by:

W. M. Woods

W. Max Woods, Thesis Advisor

H. J. Larson

Harold J. Larson, Second Reader

P. Purdue

Peter Purdue, Chairman,
Department of Operations Research

ABSTRACT

Three lower confidence interval estimation procedures for system reliability of coherent systems with cyclic components are developed and their accuracy evaluated by Monte Carlo methods. Each method uses estimates of the ratios of component unreliabilities and the Poisson approximation to the binomial distribution to obtain the equation for the lower confidence limit. This is an extension of a method previously reported in the literature which has been shown to be fairly robust. The procedures developed here can be combined with similar procedures already developed for systems with continuous components. The combined procedure may yield a reasonably accurate lower confidence interval procedure for the reliability of coherent systems with mixtures of continuous and cyclic components.



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TABLE OF CONTENTS

I. BACKGROUND	1
II. INTERVAL ESTIMATION PROCEDURES FOR SYSTEM RELIABILITY .	4
A. GENERAL CONCEPTS	4
B. PROCEDURE 1	7
C. PROCEDURE 2	8
D. PROCEDURE 3	10
E. BRIDGE SYSTEM	10
III. SIMULATION PROCEDURE	12
IV. SIMULATION RESULTS	17
A. SERIES SYSTEM	17
B. BRIDGE SYSTEM	23
V. SUMMARY AND CONCLUSIONS	25
APPENDIX A. INTERVAL ESTIMATION PROCEDURE 1	27
APPENDIX B. INTERVAL ESTIMATING PROCEDURE 2	41
APPENDIX C. INTERVAL ESTIMATING PROCEDURE 3	55
APPENDIX D. EXTERNAL SUBROUTINES	69
LIST OF REFERENCES	71
BIBLIOGRAPHY	72
INITIAL DISTRIBUTION LIST	73

LIST OF TABLES

Table 1.	INPUT NUMBER OF MISSION TRIALS N_i AND UNRELIABILITIES Q_i FOR A SERIES SYSTEM. CASES 1-3.	13
Table 2.	INPUT NUMBER OF MISSION TRIALS N_i AND UNRELIABILITIES Q_i FOR A SERIES SYSTEM. CASES 4-6.	14
Table 3.	INPUT NUMBER OF MISSION TRIALS N_i AND UNRELIABILITIES Q_i FOR A SERIES SYSTEM. CASES 7-9.	14
Table 4.	INPUT NUMBER OF MISSION TRIALS N_i AND UNRELIABILITIES Q_i FOR A SERIES SYSTEM. CASES 10-12	15
Table 5.	INPUT NUMBER OF MISSION TRIALS N_i AND UNRELIABILITIES Q_i FOR A WHEATSTONE BRIDGE. CASES 13-15.	15
Table 6.	INPUT NUMBER OF MISSION TRIALS N_i AND UNRELIABILITIES Q_i FOR A WHEATSTONE BRIDGE. CASES 16-18.	16
Table 7.	VALUES OF SCALING FACTOR K	16
Table 8.	SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE 2, CASES 1-3	17
Table 9.	SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE 2, CASES 4-6	18
Table 10.	SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE 2, CASES 7-9	18
Table 11.	SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE 2, CASES 10-12	19
Table 12.	SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE 1, CASES 1-3	19
Table 13.	SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE 1, CASES 4-6	20
Table 14.	SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE 1, CASES 7-9	20
Table 15.	SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE 1, CASES 10-12	21
Table 16.	SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE 3, CASES 1-3	21

Table 17. SUMMARY OF RESULTS FOR A SERIES-SYSTEM-PROCEDURE	
3, CASES 4-6	22
Table 18. SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE	
3, CASES 7-9	22
Table 19. SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE	
3, CASES 10-12	23
Table 20. SUMMARY OF RESULTS FOR A BRIDGE SYSTEM-PROCEDURE	
1, CASES 13-15	23
Table 21. SUMMARY OF RESULTS FOR A BRIDGE SYSTEM-PROCEDURE	
1, CASES 16-18	24
Table 22. EXPECTED NUMBER OF FAILURES.	25

LIST OF FIGURES

Figure 1. Block Diagram of a Wheatstone Bridge Structure.	11
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I. BACKGROUND

A coherent system is any system whose reliability is not reduced when the reliability of any of its components is increased. This thesis deals with coherent systems that have cyclic components. Cyclic components perform one or more repetitions of a single function during their mission. Examples are components that have power-turn-ons and power-turn-offs, switches and hydraulic units. Any component that performs a function which is regarded as a success or failure is a cyclic component. Consequently a continuously operating electronic component becomes a cyclic component if the only data for that component is the number of successes and failures in repeated trials. The number of trials to first failure of cyclic components have discrete probability distributions. Numerous approximate interval estimation procedures have been developed for system reliability of coherent systems with cyclic components. Such a method developed by Myhre and Saunders [Ref. 1: p.37] uses a likelihood ratio method. C. R. Rao [Ref. 2] developed a maximum likelihood method and Easterling [Ref. 3] proposed a modified maximum likelihood method. For special structures, such as series systems, exact methods were developed by Winterbottom [Ref. 4: pp.782-787]. Other approximate and asymptotic methods were developed by Mann and Grubbs [Ref. 5]. The accuracy of some of these approximate procedures has been studied for specific sample size cases for structures of order two or three by Mann and others [Ref. 6] and Winterbottom [Ref. 4: pp.782-787]. Woods and Borsting [Ref. 7] developed an approximate procedure which was modified extensively by Mann and Grubbs [Ref. 5: pp.335-347]. None of these discrete interval estimation procedures cited above can be readily used in conjunction with continuous component data to obtain interval estimates for the reliability of complex systems that have mixtures of cyclic and continuous components.

In this thesis we attempt to establish feasible interval estimation methods for the reliability of coherent systems with cyclic components. These methods have a common feature that allow them to be combined with similar methods that use continuous data. The combination of these methods may provide interval estimates for the reliability of systems with cyclic and continuous components. This method is an extension of a method developed by Lomnicki [Ref. 8] and extended by Myhre and others [Ref. 9: p.213]. They compare the accuracy of their procedure with the accuracy of three of the procedures cited above and provide bounds for error between the true lower confidence

bound and their approximate lower bound. These bounds are used to show that their procedure is fairly robust against errors in assumptions about the ratios between component unreliabilities which are needed to use their procedure. The procedure developed in this thesis attempts to capitalize on this robustness to extend their method by *estimating these ratios from the test data*. Specifically, let R_i denote the reliability of component i and denote component unreliability by $q_i = 1 - R_i$. Suppose the component unreliabilities of a coherent system of size k are denoted by q_1, q_2, \dots, q_k . Let

$$q_m = \max\{q_1, q_2, \dots, q_k\} \quad (1.1)$$

and $a_i = \frac{q_i}{q_m}$. Then the reliability function $h(q_1, q_2, \dots, q_k)$, of the system can be written as $h(q_m, a_1, a_2, \dots, a_k)$. Since the system is coherent, a lower confidence limit on system reliability $\hat{R}_{S,L}$ is given by

$$\hat{R}_{S,L} = h(\hat{q}_u, a_1, \dots, a_k) \quad (1.2)$$

where \hat{q}_u is the corresponding upper confidence limit on q_m . In this thesis the a_i are estimated from the data. The method developed by Myhre and others [Ref. 9: pp.216-223] assume the a_i are known.

Myhre and others [Ref. 9: p.223] also apply this failure rate ratio concept to systems whose components have exponentially distributed failure times with failure rates λ_i . In this case,

$$\lambda_m = \max\{\lambda_1, \lambda_2, \dots, \lambda_k\} \quad (1.3)$$

$$a_i = \frac{\lambda_i}{\lambda_m} \quad (1.4)$$

and $h(\hat{\lambda}_u, a_1, \dots, a_k)$ is the lower confidence limit for the reliability function $h(\lambda_m, a_1, \dots, a_k)$ where $\hat{\lambda}_u$ is the upper confidence limit for λ_m . In his thesis, Lee [Ref. 10: p.7] has demonstrated that if the same life data used to obtain $\hat{\lambda}_u$ is used to construct estimates \hat{a}_i for the a_i , in equation (1.4), then the approximate lower confidence limit

$$h(\hat{\lambda}_u, \hat{a}_1, \hat{a}_2, \dots, \hat{a}_k) \quad (1.5)$$

is an accurate approximate interval estimation procedure.

A primary reason for investigating the accuracy of this failure rate ratio method for cyclic systems is that it can be easily extended to systems that have mixtures of cyclic and continuous components. If the procedure investigated here for systems of cyclic components is found to be accurate, then it can readily be combined with the procedures established by Lee [Ref. 10: pp.3-23] to obtain an accurate interval estimation procedure for the reliability of a coherent system with a mixture of cyclic and continuous components.

An additional primary purpose of this thesis is to develop an extensive computer simulation program that will provide a means for evaluating the accuracy of proposed interval estimation methods for the reliability of coherent systems with cyclic components.

II. INTERVAL ESTIMATION PROCEDURES FOR SYSTEM RELIABILITY

A. GENERAL CONCEPTS

Consider a coherent system with k cyclic components. Mission tests for component i consist of independent Bernoulli trials administered under a mission operating environment with probability q_i of failure on each test. Then F_i , the number of failures in n_i independent mission tests, has a binomial distribution denoted by $\text{BIN}(n_i, q_i)$. We shall refer to q_i as the *unreliability* of component i .

Utilizing the concept first suggested by Lomnicki [Ref. 8: p. 109] and expanded by Myhre and others [Ref. 9: p.213], the unreliability of each component can be written as a fraction of the unreliability of the least reliable component; that is

$$q_i = a_i q_m \quad (2.1)$$

where

$q_m = \max\{q_i\}$, $i = 1, 2, \dots, k$ and $0 \leq a_i \leq 1$. We shall assume that the q_i are sufficiently small so that the probability distribution of F_i can be approximated by the Poisson distribution with mean $n_i q_i$. We denote this by the expression

$$F_i \sim P(n_i q_i). \quad (2.2)$$

Therefore, the distribution of the total number of failures, $F = \sum_{i=1}^k F_i$, can be approximated by the Poisson distribution with mean $\sum_{i=1}^k n_i q_i$; that is,

$$F \sim P\left(\sum_{i=1}^k n_i q_i\right). \quad (2.3)$$

Applying equation (2.1) to equation (2.3) we obtain

$$F \sim P\left(q_m \sum_{i=1}^k n_i a_i\right). \quad (2.4)$$

Let $h(q_1, q_2, \dots, q_k)$ denote the equation for system reliability, R_s . Then from equation (2.1),

$$R_S = h(q_m, a_1, a_2, \dots, a_k). \quad (2.5)$$

Since the system is coherent, h is non-increasing in q_m . Therefore, a lower $100(1-\alpha)\%$ confidence limit, $R_{S, L(\alpha)}$ for R_S is

$$R_{S, L(\alpha)} = h(\hat{q}_{m, u(\alpha)}, a_1, \dots, a_k) \quad (2.6)$$

where $\hat{q}_{m, u(\alpha)}$ is any $100(1-\alpha)\%$ upper confidence limit for q_m . To obtain $\hat{q}_{m, u(\alpha)}$ we use the following well known result for the upper confidence limit of the mean of a Poisson distribution, see [Ref. 11: p.218]. If $X \sim P(\lambda)$ then the upper $100(1-\alpha)\%$ confidence limit $\lambda_{u(\alpha)}$ for λ using one observation on X is

$$\lambda_{u(\alpha)} = \frac{\chi_{\alpha, 2(1+X)}^2}{2}. \quad (2.7)$$

Applying this result to equation (2.4) we obtain the upper $100(1-\alpha)\%$ confidence limit for $q_m \sum_{i=1}^k n_i a_i$, which is given by

$$\left(q_m \sum_{i=1}^k n_i a_i \right)_{u(\alpha)} = \frac{\chi_{\alpha, 2(1+F)}^2}{2}. \quad (2.8)$$

The corresponding upper confidence limit for q_m is

$$q_{m, u(\alpha)} = \frac{\chi_{\alpha, 2(1+F)}^2}{2 \sum_{i=1}^k n_i a_i}. \quad (2.9)$$

Equation (2.9) is the expression used by Myhre and others [Ref. 9 : p.214].

The components of the vector $\underline{a} = (a_1, a_2, \dots, a_k)$ as defined by Myhre and others [Ref. 9: p.214] are computed in relation to the largest unreliability q_m . However any component could be used as the base component to form a vector of ratios. Choosing the one with largest unreliability is a convenient way to select the index m . In this thesis we will assume the q_i are unknown. We will estimate them from the data. We also use the data to determine the base component, which we label component m , that will be used to form the ratio estimates \hat{a}_i . Specifically if N_i, F_i are the number of trials and resultant failures for component i , then $\hat{q}_i = \frac{F_i}{N_i}$ is the estimate of unreliability q_i . Hereafter in this thesis, we define the index m by the equation

$$\hat{q}_m = \max(\hat{q}_1, \hat{q}_2, \dots, \hat{q}_k). \quad (2.10)$$

We shall define \hat{a}_i by

$$\hat{a}_i = \frac{\hat{q}_i}{\hat{q}_m} \quad i = 1, 2, \dots, k. \quad (2.11)$$

Note that \hat{q}_m is *not intended* to be an estimate of $\max(q_1, \dots, q_k)$. It is nothing more than the largest of the observed estimates of the component unreliabilities and provides us with the base-component which we denote by m . Hereafter, in this thesis, q_m will denote the unreliability of the component m which has been determined by the definition of \hat{q}_m . With the index m determined and the quantities $\hat{a}_1, \hat{a}_2, \dots, \hat{a}_k$ computed, we can compute an approximate upper confidence limit $\hat{q}_{m,u(\alpha)}$ for q_m that corresponds to $q_{m,u(\alpha)}$ in equation (2.9). Specifically,

$$\hat{q}_{m,u(\alpha)} = \frac{\chi_{\alpha, 2(1+F)}^2}{2 \sum_{i=1}^k n_i \hat{a}_i}. \quad (2.12)$$

The corresponding approximate lower $100(1-\alpha)\%$ confidence limit $\hat{R}_{S,L(\alpha)}$ is

$$h(\hat{q}_{m,u(\alpha)}, \hat{a}_1, \dots, \hat{a}_k). \quad (2.13)$$

We have special problems with equation (2.12) when none of the components fail. In this case $\hat{q}_i = 0$, ($i = 1, 2, \dots, k$) $\hat{q}_m = 0$ and all \hat{a}_i are undefined. If at least one component has at least one failure, equation (2.12) is well defined. Consequently, equations (2.12) and (2.13) must be modified or supplemented to account for cases when none or perhaps only one of the components fail. In fact we may want to modify the definition of \hat{a}_i whenever $\hat{a}_i = 0$; i.e. when $F_i = 0$. Anytime $\hat{a}_i = 0$, the N_i tests for component i make no contribution toward the evaluation of $\hat{q}_{m,u(\alpha)}$ in equation (2.12). If information about the range of $a_i \equiv \frac{q_i}{q_m}$ is known, it could be used to redefine \hat{a}_i so that $\hat{a}_i n_i$ in the denominator of equation (2.12) would not be zero. This is mathematically equivalent to adding $\hat{a}_i n_i$ tests to the N_m tests for component m without adding any failures to F_m . This is the one advantage of the ratio method and it is reflected in both equations (2.12) and (2.13). It is this specific property of the ratio method that makes it particularly appealing when the total number of failures is small.

The primary purpose of this thesis is to initiate the development of alternative methods for constructing approximate lower confidence limits $R_{S, L(\alpha)}$ for the reliability R_S of coherent systems that account for zero or nearly zero failures and to construct a computer program that can be used to evaluate the accuracy of these confidence limit procedures. It is highly desirable that these methods make strong use of the ratio method, when several types of components experience failure, because doing so should allow us to extend these confidence limit procedures to systems that have both cyclic and continuously operating types of components.

It is highly unlikely that any one confidence limit procedure will be reasonably accurate for all system configurations; i.e., for all reliability functions, $h(q_1, \dots, q_k)$. Consequently, we have developed three similar procedures which are labeled Procedure 1, 2, and 3. Each of these procedures will be evaluated for accuracy when applied to two radically different types of system configurations; namely series system and Wheatstone bridge systems. Series systems have no redundant components. Wheatstone bridges are highly redundant systems. These accuracy evaluations should help establish some preliminary boundary constraints on the application of these procedures and provide insights for modifications that may yield more accurate procedures.

The first evaluations will be performed for a series system of k independent components. In this case the system reliability R_S is given by $R_S = \prod_{i=1}^k (1 - q_i) = \prod_{i=1}^k (1 - a_i q_m)$ where q_i denotes the unreliability of component i , and m will be the index established by the data as previously discussed, and $a_i = \frac{q_i}{q_m}$. One expression that can be used to construct a lower $100(1-\alpha)\%$ confidence limit $R_{S, L(\alpha)}$ for R_S using $\hat{q}_{m, u(\alpha)}$ given in equation (2.12) is

$$\hat{R}_{S, L(\alpha)} = \prod_{i=1}^k (1 - \hat{a}_i \hat{q}_{m, u(\alpha)}). \quad (2.14)$$

In the following descriptions, n_i and F_i denote the number of tests (Bernoulli trials) and the number of failures, respectively, for component i , $i = 1, 2, \dots, k$.

B. PROCEDURE 1

This procedure has three expressions for $\hat{R}_{S, L(\alpha)}$ which depend on the test results F_1, F_2, \dots, F_k . If no components fail, all $\hat{q}_i = 0$, and all \hat{a}_i are undefined. This precludes the use of equation (2.12) to construct $\hat{R}_{S, L(\alpha)}$ for this case. When no components fail, we define

$$n^* = \min(n_1, n_2, \dots, n_k) \quad (2.15)$$

and interpret the data as n^* successful system tests. Rather than use the standard approximate binomial confidence limit $(\alpha)^{\frac{1}{n^*}}$, we choose to define $\hat{R}_{S, L(\alpha)}$ by

$$\hat{R}_{S, L(\alpha)} = 1 - \frac{\chi_{\alpha, 2}^2}{2 n^*} \quad (2.16)$$

This expression reflects the Poisson approximation to the Binomial distribution and will be slightly conservative when all $F_i = 0$, but the other components to Procedure 1 are suspected to be slightly optimistic. So the entire procedure may be nearly exact. If the entire procedure is conservative, we can always change equation (2.16).

The second expression in Procedure 1 addresses the case when all but one component, say component 1, have zero failures. For a series system, this would correspond to at most one system failure out of n^* system tests. This would not be the case in other systems if the failed component is redundant in the system. Here again we choose slightly conservative procedure for the lower confidence limit; namely, we define $\hat{q}_{1, u(\alpha)}$ by

$$\hat{q}_{1, u(\alpha)} = \frac{\chi_{\alpha, 2(1+F_1)}^2}{2 n_1} \quad (2.17)$$

We use equation (2.13) to define $\hat{R}_{S, L(\alpha)}$ for a general coherent system. If the system is a series system we use equation (2.14).

The third expression in Procedure 1 addresses the case when at least two different types of components have failures; that is, $F_i \neq 0$ for at least two values of i ,

$i = 1, 2, \dots, k$. In this case we use equation (2.12) to define $\hat{q}_{m, u(\alpha)}$ where $\hat{a}_i = \frac{\hat{q}_i}{\hat{q}_m}$, $\hat{q}_i = \frac{F_i}{n_i}$ and $\hat{q}_m = \max(\hat{q}_1, \dots, \hat{q}_k)$. The lower confidence limit for the system is given by equation (2.13) for general coherent systems or equation (2.14) for a series system.

C. PROCEDURE 2

Procedure 2 differs from Procedure 1 in two respects. First, we assume that at least two different components of the system have at least one failure. Operationally this means that Procedure 2 would only be applied to data for which at least two types of system components experienced one or more failures. In this procedure we always use

equation (2.1) to obtain $\hat{q}_{m, u(a)}$ and equation (2.13) or (2.14) to compute $\hat{R}_{S, L(a)}$ for general

coherent systems or series systems respectively. Again $\hat{a}_i = \frac{\hat{q}_i}{\hat{q}_m}$, but we will define \hat{q}_i differently for components with zero failures. Specifically, we apply a common scaling factor K to increase the sample size from n_i to Kn_i for all system components i which experienced zero failures and record 1 failure for each of those components. For example, if n_1 , n_2 and n_3 tests were performed on component types 1, 2 and 3 and no failures occurred on any of these tests, the data is modified to show $F_1 = 1$, $F_2 = 1$, $F_3 = 1$ and new sample sizes Kn_1 , Kn_2 and Kn_3 . The scaling factor is an input parameter to the computer programs used to evaluate this procedure; ie., it is assumed to be known. It is determined by

$$K = \frac{\max(q_1, \dots, q_k)}{\min(q_1, \dots, q_k)} = \frac{q_{\max}}{q_{\min}} \quad (2.18)$$

where the q_i are the component unreliabilities. Operationally, this would mean that the user of this procedure must determine an estimate for this ratio. Previous data is often available to provide this estimate. Such estimates can sometimes be constructed from Department of Defense (DOD) documents that provide a variety of quality data characteristics for hardware purchased in accordance with prescribed standards and specifications; e.g., MILHDBK-217E and its referenced documents. Also the reliability values for components used in reliability prediction analysis are usually derived from some official source which could be satisfactory for such estimates. A reliability prediction analysis is usually required in any major DOD system acquisition program. If a satisfactory estimate for K cannot be obtained, then Procedure 2 should not be used. Of course one of the purposes of this thesis is to investigate the accuracy of this procedure when the scaling factor K is chosen "correctly"; i.e., according to equation (2.18). Thinking of q_{\max} and q_{\min} as failure rates, $\frac{1}{q_{\max}}$ and $\frac{1}{q_{\min}}$ denote the expected number of tests to first failure for their respective components. Then the value K in equation (2.18) is the ratio of these two expected number of tests to obtain one failure for each component. That is,

$$K = \left(\frac{1}{q_{\min}} \right) / \left(\frac{1}{q_{\max}} \right). \quad (2.19)$$

For each system component i that experiences zero failures, the corresponding estimate \hat{q}_i for q_i is given by

$$\hat{q}_i = \frac{1}{K n_i} \quad (2.20)$$

Then

$$\hat{a}_i = \frac{\hat{q}_i}{\hat{q}_m} \quad (2.21)$$

and

$$\hat{q}_{m,u(x)} = \frac{\chi_{\alpha, 2(1+F)}^2}{2 \sum_{i=0}^k n_i \hat{a}_i} \quad (2.22)$$

where F is the number of actual failures observed before the data is adjusted. Thus the data is adjusted to obtain estimated values \hat{a}_i different from zero for those components that have no failures. The value for $\hat{R}_{S, L(s)}$ is given by equation (2.14). Note that if all k types of components have at least one failure, the resulting value of $\hat{R}_{S, L(s)}$ is the same under Procedures 1 and 2.

D. PROCEDURE 3

Procedure 3 differs from Procedure 1 in only one respect. We scale the sample sizes as we did in Procedure 2. That is, for each system component i that has no failures, we estimate q_i from equation (2.20). Equations for \hat{a}_i , $\hat{q}_{m,(s)}$ and $\hat{R}_{S, L(s)}$ are given by equations (2.21), (2.22) and (2.13) or (2.14) respectively.

Procedure 3 does not require that at least one failure have occurred on at least two different types of components as required in Procedure 2. Operationally, Procedure 3 can be used for all sets of data including those sets where no failures occur.

E. BRIDGE SYSTEM

We define a Wheatstone bridge system by the reliability block diagram shown in Figure 1 on page 11. If p_i denotes the reliability of component i , $i = 1, 2, \dots, 5$, and $1 - p_i \equiv q_i = a_i q_m$ where $q_m = \max\{q_1, q_2, \dots, q_5\}$, then system reliability R_S is given by

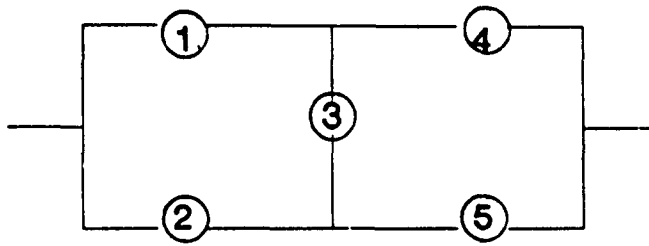


Figure 1. Block Diagram of a Wheatstone Bridge Structure.

$$\begin{aligned}
 R_S &= h(q_m, a_1, \dots, a_5) \\
 &= 1 - q_m^2(a_1 a_2 + a_4 a_5) - q_m^3(a_1 a_3 a_5 + a_2 a_3 a_4) \\
 &\quad + q_m^4(a_1 a_2 a_3 a_4 + a_1 a_2 a_3 a_5 + a_1 a_2 a_4 a_5 + a_1 a_3 a_4 a_5 + a_2 a_3 a_4 a_5) \\
 &\quad - 2q_m^5(a_1 a_2 a_3 a_4 a_5)
 \end{aligned} \tag{2.23}$$

(see Myhre and others [Ref. 9: p.215]).* Then the equation for the lower $100(1-\alpha)\%$ confidence limit on this system is

$$\hat{R}_{S, L(\alpha)} = h(\hat{q}_{m, u(\alpha)}, \hat{a}_1, \dots, a_5) \tag{2.24}$$

where $\hat{q}_{m, u(\alpha)}$ and \hat{a}_i are defined as in Procedures 1, 2 or 3. Only Procedure 1 was evaluated for the bridge system and reported in this thesis.

III. SIMULATION PROCEDURE

Standard computer simulation methods were used to evaluate the accuracy of the three interval estimation methods discussed in section II. The input parameters needed to run the computer programs for each of the three interval estimation procedures are as follows:

- k : number of components in the system
- $\underline{n} = (n_1, n_2, \dots, n_k)$: vector of sample sizes (mission tests)
- $\underline{q} = (q_1, q_2, \dots, q_k)$: vector of component unreliabilities
- α : level of confidence

The NON-IMSL uniform random number generator SRND was used to simulate the outcomes of mission tests on the k components. A total of $\sum_{i=1}^k n_i$ uniform random numbers were generated and transformed into ones or zeroes as follows: the n_i numbers $x_{i1}, x_{i2}, \dots, x_{in_i}$ in the i th block of uniform random numbers were transformed by the expression

$$Y_{ij} = 1 \quad \text{if } x_{ij} \leq q_i$$

$$Y_{ij} = 0 \quad \text{if } x_{ij} > q_i$$

for $j = 1, 2, \dots, n_i$, and $i = 1, 2, \dots, k$, where q_i is the input parameter denoting the unreliability of component i . Then $F_i = \sum Y_{ij}$ denotes the number of failures in n_i independent Bernoulli trials. This set of data is used to compute the values of \hat{q}_i , $\hat{\alpha}_i$, $\hat{q}_{m, u(s)}$ and $\hat{R}_{S, L(s)}$ for each of the three interval estimation methods. Thus one realization of the lower bound estimate $\hat{R}_{L(s), 1}$ for the random variable $\hat{R}_{S, L(s)}$ is obtained for each set of $\sum_{i=1}^k n_i$ uniform random numbers generated. Each realization described was replicated 1000 times in order to generate a simulated empirical population of this random variable $\hat{R}_{S, L(s)}$. The vector of replications thus obtained was sorted from smallest to largest to obtain $\hat{R}_{L(s), (1)}, \dots, \hat{R}_{L(s), (1000)}$. Then the $100(1-\alpha)\%$ approximate lower confidence bound on the true system reliability R_S is the $1000(1-\alpha)$ th element of the sorted vector of replications; namely, $\hat{R}_{L(s), (1000(1-\alpha))}$.

The simulated true confidence level is calculated by finding the element of the vector of replications which is closest to R_S and observing its index number j . Then the simu-

lated "true" confidence level is $\frac{j}{1000} \times 100$. If there is a sequence of indices with the same value closest to R_s , we chose the smallest index j . This may yield an arbitrarily small value for our recorded "true" confidence level.

In addition to the external subroutines programmed by the author and to the ones mentioned above, the following subroutines were used:

- IMSL subroutine MDCHI was used to calculate the value of a chi-square random variable given the quantile and the degrees of freedom.
- NON-IMSL subroutine SHSORT was used to sort the arrays of system reliability estimates in ascending order in order to obtain the appropriate order statistic.
- IMSL subroutine USNMNMX was used to extract the minimum and maximum values of the vector of mission tests for each component and of the vector of input component unreliabilities.

Each set of input parameters defines a simulation run, or a case. The following tables specify the sets of parameters used for each case that was simulated.

Table 1. INPUT NUMBER OF MISSION TRIALS N_i AND UNRELIABILITIES Q_i FOR A SERIES SYSTEM. CASES 1-3.

Component no.	n_i by Case Number			Input q_i (cases 1-3)
	1	2	3	
1	100	50	30	0.0200
2	30	30	25	0.0100
3	15	10	20	0.0050
4	10	10	10	0.0050
5	5	5	5	0.0050

Table 2. INPUT NUMBER OF MISSION TRIALS N_i AND UNRELIABILITIES Q_i FOR A SERIES SYSTEM. CASES 4-6.

Component no.	n_i by Case Number			Input q_i (cases 4-6)
	4	5	6	
1	100	50	30	0.0100
2	30	30	25	0.0050
3	15	10	20	0.0025
4	10	10	10	0.0025
5	5	5	5	0.0025

Table 3. INPUT NUMBER OF MISSION TRIALS N_i AND UNRELIABILITIES Q_i FOR A SERIES SYSTEM. CASES 7-9.

Component no.	n_i by Case Number			Input q_i (cases 7-9)
	7	8	9	
1	100	50	30	0.0200
2	30	30	25	0.0100
3	15	15	20	0.0050
4	10	5	15	0.0050
5	10	5	10	0.0050
6	10	5	5	0.0050
7	10	5	5	0.0050
8	10	5	5	0.0050
9	10	5	5	0.0050
10	10	5	5	0.0050

Table 4. INPUT NUMBER OF MISSION TRIALS N_i AND UNRELIABILITIES Q_i FOR A SERIES SYSTEM. CASES 10-12

Component no.	n_i by Case Number			Input q_i (cases 10-12)
	10	11	12	
1	100	50	30	0.0100
2	30	30	25	0.0050
3	15	15	20	0.0025
4	10	5	15	0.0025
5	10	5	10	0.0025
6	10	5	5	0.0025
7	10	5	5	0.0025
8	10	5	5	0.0025
9	10	5	5	0.0025
10	10	5	5	0.0025

Table 5. INPUT NUMBER OF MISSION TRIALS N_i AND UNRELIABILITIES Q_i FOR A WHEATSTONE BRIDGE. CASES 13-15.

Component no.	n_i by Case Number			Input q_i (cases 13-15)
	13	14	15	
1	100	50	30	0.1000
2	30	30	25	0.0700
3	15	10	20	0.0700
4	10	10	10	0.0700
5	5	5	5	0.0700

Table 6. INPUT NUMBER OF MISSION TRIALS N_i AND UNRELIABILITIES Q_i FOR A WHEATSTONE BRIDGE. CASES 16-18.

Component no.	n_i by Case Number			Input q_i (cases 16-18)
	16	17	18	
1	100	50	30	0.0500
2	30	30	25	0.0350
3	15	10	20	0.0350
4	10	10	10	0.0350
5	5	5	5	0.0350

The values of the scaling factor K used in Procedures 2 and 3 are as follows:

Table 7. VALUES OF SCALING FACTOR K .

Case Number	K
1-12	4
13-18	1.43

These values are computed from the assigned input parameters for these cases; e.g.,
 $4 = \frac{.01}{.0025}$ from table 4 and $1.43 \approx \frac{.05}{.035}$ from table 6.

IV. SIMULATION RESULTS

The results of the simulation runs for the twelve series system cases are presented in Tables 8 through 19. The results of the simulation runs for the six bridge system cases are presented in Tables 20 and 21. The accuracy of a particular interval estimation procedure for each case can be assessed from these tables. If the interval estimation procedure is exact, the two values R_S and $\hat{R}_{L(\alpha), 1000(1-\alpha)}$ would be equal and the True Confidence Level value would be $100(1-\alpha)$. For example, consider Table 8, case 2 and $\alpha = .20$. True system reliability, R_S is 0.95572 and $\hat{R}_{L(\alpha), 1000(1-\alpha)} = 0.96398$. Thus the simulations indicate that the 80th percentile point of the distribution of $\hat{R}_{L(\alpha)}$ for Procedure 2 for case 2 is 0.964 instead of 0.956. This error reflects the inaccuracy of the approximate 80% lower confidence limit $\hat{R}_{S, L(\alpha, 20)}$ as defined under Procedure 2. The table also indicates that $R_S \equiv 0.95572$ is approximately the 77.4 percentile point of the distribution of $\hat{R}_{S, L(\alpha, 20)}$ instead of the 80th percentile point.

The number of components in the system that had zero failures in each of the 1000 replications was recorded. The average of the 1000 values is displayed in the last column of the table.

A. SERIES SYSTEM

Table 8. SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE 2, CASES 1-3

No. of Compnts	Case no.	Significance Level	R_S	$\hat{R}_{L(\alpha), 1000(1-\alpha)}$	True Confidence Level	Avg. no. of comp. with no failure
5	1	$\alpha = .20$	0.95572	0.93563	93.20	3.71
		$\alpha = .05$	0.95572	0.93981	100.00	3.71
	2	$\alpha = .20$	0.95572	0.96398	77.40	3.98
		$\alpha = .05$	0.95572	0.93366	100.00	3.98
	3	$\alpha = .20$	0.95572	0.96633	65.40	4.16
		$\alpha = .05$	0.95572	0.93793	100.00	4.16

increase.

Table 9. SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE
2, CASES 4-6

No. of Compnts	Case no.	Signif- icance Level	R_s	$\hat{R}_{L(\alpha), 1000(1-\alpha)}$	True Con- fidence Level	Avg. no. of comp. with no failure
5	4	$\alpha = .20$	0.97768	0.96737	100.00	4.15
		$\alpha = .05$	0.97768	0.93981	100.00	4.15
	5	$\alpha = .20$	0.97768	0.96398	100.00	4.40
		$\alpha = .05$	0.97768	0.93366	100.00	4.40
	6	$\alpha = .20$	0.97768	0.96633	100.00	4.55
		$\alpha = .05$	0.97768	0.93793	100.00	4.55

Table 10. SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE
2, CASES 7-9

No. of Compnts	Case no.	Signif- icance Level	R_s	$\hat{R}_{L(\alpha), 1000(1-\alpha)}$	True Con- fidence Level	Avg. no. of comp. with no failure
10	7	$\alpha = .20$	0.93206	0.93884	77.30	8.49
		$\alpha = .05$	0.93206	0.94091	94.30	8.49
	8	$\alpha = .20$	0.93206	0.88770	81.00	8.86
		$\alpha = .05$	0.93206	0.89162	100.00	8.86
	9	$\alpha = .20$	0.93206	0.94925	70.60	9.01
		$\alpha = .05$	0.93206	0.90729	100.00	9.01

increase.

Table 11. SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE
2, CASES 10-12

No. of Compnts	Case no.	Signif- icance Level	R_s	$\hat{R}_{L(\alpha), 1000(1-\alpha)}$	True Con- fidence Level	Avg. no. of comp. with no failure
10	10	$\alpha = .20$	0.96552	0.96788	75.30	9.03
		$\alpha = .05$	0.96552	0.94091	100.00	9.03
	11	$\alpha = .20$	0.96552	0.94046	100.00	9.36
		$\alpha = .05$	0.96552	0.89162	100.00	9.36
	12	$\alpha = .20$	0.96552	0.94925	100.00	9.48
		$\alpha = .05$	0.96552	0.90729	100.00	9.48

Table 12. SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE
1, CASES 1-3

No. of Compnts	Case no.	Signif- icance Level	R_s	$\hat{R}_{L(\alpha), 1000(1-\alpha)}$	True Con- fidence Level	Avg. no. of comp. with no failure
5	1	$\alpha = .20$	0.95572	0.95721	65.20	3.70
		$\alpha = .05$	0.95572	0.95254	100.00	3.70
	2	$\alpha = .20$	0.95572	0.94011	100.00	3.97
		$\alpha = .05$	0.95572	0.90508	100.00	3.97
	3	$\alpha = .20$	0.95572	0.90018	100.00	4.14
		$\alpha = .05$	0.95572	0.84181	100.00	4.14

increase.

Table 13. SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE 1, CASES 4-6

No. of Compnts	Case no.	Significance Level	R_s	$\hat{R}_{L(\alpha), 1000(1-\alpha)}$	True Confidence Level	Avg. no. of comp. with no failure
5	4	$\alpha = .20$	0.97768	0.97005	100.00	4.14
		$\alpha = .05$	0.97768	0.95254	100.00	4.14
	5	$\alpha = .20$	0.97768	0.94011	100.00	4.38
		$\alpha = .05$	0.97768	0.90508	100.00	4.38
	6	$\alpha = .20$	0.97768	0.88021	100.00	4.53
		$\alpha = .05$	0.97768	0.84181	100.00	4.53

Table 14. SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE 1, CASES 7-9

No. of Compnts	Case no.	Significance Level	R_s	$\hat{R}_{L(\alpha), 1000(1-\alpha)}$	True Confidence Level	Avg. no. of comp. with no failure
10	7	$\alpha = .20$	0.93206	0.95721	59.80	8.48
		$\alpha = .05$	0.93206	0.95254	74.40	8.48
	8	$\alpha = .20$	0.93206	0.94011	75.90	8.85
		$\alpha = .05$	0.93206	0.90508	100.00	8.85
	9	$\alpha = .20$	0.93206	0.88021	100.00	8.99
		$\alpha = .05$	0.93206	0.84181	100.00	8.99

increase.

Table 15. SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE
1, CASES 10-12

No. of Compts	Case no.	Significance Level	R_s	$\hat{R}_{L(\alpha), 1000(1-\alpha)}$	True Confidence Level	Avg. no. of comp. with no failure
10	10	$\alpha = .20$	0.96552	0.97005	74.40	9.02
		$\alpha = .05$	0.96552	0.95234	100.00	9.02
	11	$\alpha = .20$	0.96552	0.94011	100.00	9.35
		$\alpha = .05$	0.96552	0.90508	100.00	9.35
	12	$\alpha = .20$	0.96552	0.88021	100.00	9.44
		$\alpha = .05$	0.96552	0.84181	100.00	9.44

Table 16. SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE
3, CASES 1-3

No. of Compts	Case no.	Significance Level	R_s	$\hat{R}_{L(\alpha), 1000(1-\alpha)}$	True Confidence Level	Avg. no. of comp. with no failure
5	1	$\alpha = .20$	0.95572	0.93563	93.20	3.70
		$\alpha = .05$	0.95572	0.93981	100.00	3.70
	2	$\alpha = .20$	0.95572	0.96398	77.30	3.97
		$\alpha = .05$	0.95572	0.93366	100.00	3.97
	3	$\alpha = .20$	0.95572	0.96633	65.40	4.14
		$\alpha = .05$	0.95572	0.93793	100.00	4.14

increase.

Table 17. SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE
3, CASES 4-6

No. of Compnts	Case no.	Signif- icance Level	R_S	$\hat{R}_{L(\alpha), 1000(1-\alpha)}$	True Con- fidence Level	Avg. no. of comp. with no failure
5	4	$\alpha = .20$	0.97768	0.96737	100.00	4.14
		$\alpha = .05$	0.97768	0.93981	100.00	4.14
	5	$\alpha = .20$	0.97768	0.96398	100.00	4.38
		$\alpha = .05$	0.97768	0.93366	100.00	4.38
	6	$\alpha = .20$	0.97768	0.96633	100.00	4.53
		$\alpha = .05$	0.97768	0.93793	100.00	4.53

Table 18. SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE
3, CASES 7-9

No. of Compnts	Case no.	Signif- icance Level	R_S	$\hat{R}_{L(\alpha), 1000(1-\alpha)}$	True Con- fidence Level	Avg. no. of comp. with no failure
10	7	$\alpha = .20$	0.93206	0.93884	77.30	8.48
		$\alpha = .05$	0.93206	0.94091	94.30	8.48
	8	$\alpha = .20$	0.93206	0.88770	80.80	8.85
		$\alpha = .05$	0.93206	0.89162	100.00	8.85
	9	$\alpha = .20$	0.93206	0.94925	70.40	8.99
		$\alpha = .05$	0.93206	0.90729	100.00	8.99

increase.

Table 19. SUMMARY OF RESULTS FOR A SERIES SYSTEM-PROCEDURE
3, CASES 10-12

No. of Compnts	Case no.	Significance Level	R_s	$\hat{R}_{L(\alpha), 1000(1-\alpha)}$	True Confidence Level	Avg. no. of comp. with no failure
10	10	$\alpha = .20$	0.96552	0.96788	75.30	9.02
		$\alpha = .05$	0.96552	0.94091	100.00	9.02
	11	$\alpha = .20$	0.96552	0.94046	100.00	9.35
		$\alpha = .05$	0.96552	0.89162	100.00	9.35
	12	$\alpha = .20$	0.96552	0.94925	100.00	9.44
		$\alpha = .05$	0.96552	0.90729	100.00	9.44

B. BRIDGE SYSTEM

Table 20. SUMMARY OF RESULTS FOR A BRIDGE SYSTEM-PROCEDURE
1, CASES 13-15

No. of Compnts	Case no.	Significance Level	R_s	$\hat{R}_{L(\alpha), 1000(1-\alpha)}$	True Confidence Level	Avg. no. of comp. with no failure
5	13	$\alpha = .20$	0.98742	0.99372	56.6	1.64
		$\alpha = .05$	0.98742	1.00000	71.50	1.64
	14	$\alpha = .20$	0.98742	0.99332	59.30	1.78
		$\alpha = .05$	0.98742	1.00000	77.20	1.78
	15	$\alpha = .20$	0.98742	0.99333	59.60	1.57
		$\alpha = .05$	0.98742	1.00000	80.10	1.57

increase.

Table 21. SUMMARY OF RESULTS FOR A BRIDGE SYSTEM-PROCEDURE 1, CASES 16-18

No. of Compnts	Case no.	Signif- icance Level	R_s	$\hat{R}_{L(\alpha), 1000(1-\alpha)}$	True Con- fidence Level	Avg. no. of comp. with no failure
5	16	$\alpha = .20$	0.94816	0.96354	62.60	0.77
		$\alpha = .05$	0.94816	0.97426	77.70	0.77
	17	$\alpha = .20$	0.94816	0.96122	64.10	0.94
		$\alpha = .05$	0.94816	0.96740	82.80	0.94
	18	$\alpha = .20$	0.94816	0.95858	69.70	0.73
		$\alpha = .05$	0.94816	0.97125	86.30	0.73

V. SUMMARY AND CONCLUSIONS

The results in Tables 8 through 19 in section IV are quite mixed with respect to the accuracy across all twelve cases. However, these results definitely indicate that any one of the three interval estimation procedures offers excellent potential for a reasonably accurate lower confidence interval estimation method for system reliability. The accuracy of approximate discrete interval estimation methods for system reliability in general depend on the amount of testing relative to the expected number of failures, $\sum_{i=1}^k n_i q_i$. Woods and Borsting [Ref. 7] for example, show their lower confidence limit procedure to be quite accurate for cases for which the expected number of failures is greater than 5. The expected number of failures for some of the cases simulated in this thesis are as follows:

Table 22. EXPECTED NUMBER OF FAILURES

Case No.:	1	4	7	10	13	14	16
$\sum_{i=1}^k n_i q_i$	2.45	1.225	2.725	1.362	14.2	8.85	6.8

Consequently, any cases other than those numbered 13, 14, and 16 should not be expected to be highly accurate if these three procedures have features similar to those of the Woods-Borsting procedure [Ref. 7 : p.1]. Actually, in light of the small values of $\sum_{i=1}^k n_i q_i$ for cases 1, 4, 7, and 10, it is somewhat surprising that the procedures are as accurate as they are at the 80% level of confidence. The results for cases 13, 14, and 16 are quite good at the 80% level of confidence for the bridge system. Some of the parameter sets for the cases run were designed to detect instances where the methods might not be accurate.

The three procedures analyzed in this thesis should be modified and combined to establish one general procedure. The corresponding range of parameter sets for which the procedure is accurate should be established. This range will likely be a function of $\sum_{i=1}^k n_i q_i$. This kind of a procedure could be useful in many practical settings. Moreover,

it could be combined with the method developed in the thesis by Lee [Ref. 10: pp.3-23]. Additional analysis, and simulation need to be performed to establish such a procedure.

APPENDIX A. INTERVAL ESTIMATION PROCEDURE 1

PROGRAM ZFYSCN

```
*
* TITLE: BINOMIAL INTERVAL ESTIMATION PROCEDURE
* ZERO FAILURES ALLOWED; NO SCALING
* AUTHOR: E. F. BELLINI, LT, USN
* DATE: NOV 89
*
```

```
*
* THIS PROGRAM COMPUTES THE TRUE CONFIDENCE LEVEL FOR THE ESTIMATE
* RELIABILITY OF A SERIES AND BRIDGE SYSTEM GIVEN THE RELIABILITY
* OF THEIR COMPONENTS
*
```

```
*
* IN ITS PRESENT CONFIGURATION THIS PROGRAM IS SET UP TO RUN 12
* TIMES EACH TIME PRODUCING 1000 REPLICATIONS USING A DIFFERENT
* SET OF INPUT DATA. RUN THE PROGRAM FROM CMS BY TYPING 'B1 EXEC'.
* THE REXX EXEC PROGRAM
* 'B1' CALLS THE INPUT FILES TO BE READ AND NAMES THE 12 OUTPUT
* FILES RESULTING FROM THE 12 CONSECUTIVE RUNS. BY EDITING THE
* INDEX COUNTERS I, J, K OF THE 'B1' EXEC ONE CAN RUN ANY USER-
* SPECIFIC RUN FROM JUST ONE RUN TO ALL 12.
*
```

VARIABLES USED

```
*
* AHATI : WEIGHT ESTIMATES FOR EACH COMPONENT
* AI : INPUT WEIGHTS FOR EACH COMPONENT
* ALFA : LEVELS OF SIGNIFICANCE
* BIGF : TOTAL NO. OF FAILURES FOR EACH REPLICATION
* CHISQ : CHI-SQUARE RANDOM VARIABLE VALUE
* C1C15 : FORMAT LABEL
* DEGFR : DEGREES OF FREEDOM
* DELBRG : DIFFERENCE FOR BRIDGE SYSTEM
* DELSTR : DIFFERENCE FOR SERIES SYSTEM- CLOSED FORM
* DELTAR : DIFFERENCE FOR SERIES SYSTEM
* DIFF : DIFFERENCE (TRUE REL. - ESTIMATED REL.)
* EPS : SMALL QUANTITY(CONSTANT)
* ERROR : PARAMETER FOR IMSL ROUTINE
* FAILS : COUNTS NO. OF REPLICATIONS WITH AT LST. 1 FAILURE
* FI : NO. OF FAILURES FOR EACH COMPONENT(ALL MISSION TST)*
* FLAG : 1 IF ALL COMP. HAVE SAME NO. OF MISSION TESTS
* INC : INCREMENT STEP SIZE FOR ROUTINE USNMNMX
* KEY1 : ARRAY OF INDECS FOR ROUTINE SHSORT
* KEY2 : ARRAY OF INDECS FOR ROUTINE SHSORT
* KEY3 : ARRAY OF INDECS FOR ROUTINE SHSORT
* KEY4 : ARRAY OF INDECS FOR ROUTINE SHSORT
* KK : ARRAY SIZING PARAMETER FOR THE MAX NO OF COMPONENTS*
* LOOP : COUNTS NO. OF REPLICATION PERFORMED
* MAXALF : MAX NO. OF SIGNIFICANT LEVELS DESIRED(ARRAY SIZING)*
* MAXREP : MAX NO. OF REPLICATIONS
* MAXRUN : MAX NO. OF PROGRAM ITERATIONS ALLOWED
* MSTRQ : MASTER UNRELIABILITY(USED WITH AI'S TO CALC. QI'S)
* MULT : MULTIPLIER FOR RANDOM NO. GENERATOR SRN
*
```

```

*      N      : NO. OF MISSION TEST FOR EACH COMPONENT      *
*      NIMAX   : MAX NO. OF MISSION TESTS                    *
*      NIMIM   : MIN NO. OF MISSION TESTS                    *
*      NINDX   : INDEX NO. OF MAX NO. OF MISSION TESTS      *
*      NIREAL  : NO. OF MISSION TESTS TRANSFORMED TO REAL    *
*      NMAX    : MAX NO. OF MISSION TESTS FOR OUTPUT CONTROL *
*      NPRNT   : FLAG FOR DETAILED REPORT OUTPUT             *
*      PRNT    : SAME AS ABOVE(PARAMETER)                    *
*      QHATI   : UNRELIABILITY ESTIMATES FOR EACH COMPONENT *
*      QHTMAX  : LARGEST QHATI                                *
*      QHTUPR  : UPPER LIMIT ON SYSTEM UNRELIABILITY         *
*      QI      : INPUT UNRELIABILITY FOR EACH COMPONENT      *
*      QINDX   : INDEX                                        *
*      QUANTL  : QUANTILE                                     *
*      REPSHD  : REPLICATIONS HEADING FORMAT NUMBER          *
*      RHTSTR  : SERIES SYSTEM RELIABILITY ESTIMATE(CLOSED FORM) *
*      RS      : TRUE SERIES SYSTEM RELIABILITY              *
*      RSBRDG  : TRUE BRIDGE SYSTEM RELIABILITY              *
*      RSHAT   : SERIES SYSTEM RELIABILITY ESTIMATE          *
*      RSHTBR  : BRIDGE SYSTEM RELIABILITY ESTIMATE          *
*      SEED    : PARAMETER                                    *
*      SELCTA  : SIGNIFICANCE LEVEL SELECTION                *
*      SELCTB  : SIGNIFICANCE LEVEL SELECTION                *
*      SORT    : PARAMETER FOR ROUTINE SRND                  *
*      SUMNAI  : SUM OF THE PRODUCT OF NI'S AND AI'S         *
*      TEMP    : TEMPORARY ARRAY                             *
*      TOTREP  : TOTAL NUMBER OF PROGRAM ITERATIONS          *
*      TRANBR  : TEMPORARY ARRAY                             *
*      TRANSQ  : TEMPORARY ARRAY                             *
*      TRANSR  : TEMPORARY ARRAY                             *
*      TRIALS  : BERNOULLI TRIALS ARRAY (2-DIM)              *
*      TRNSTR  : TEMPORARY ARRAY                             *
*      TRUQNT  : TRUE QUANTILE                                *
*      UNIRV   : UNIFORM RANDOM DEVIATES (2-DIM)            *
*      ZFAILS  : TOTAL NUMBER OF REPLICATIONS WITH ZERO FAILURES *
*      ZFPREP  : NO. OF COMPTS. WITH ZERO FAILURES PER REPLICATION *

```

```

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

```

```

PARAMETER (KK=10,MAXALF=2,NPRNT=0)
PARAMETER (MAXREP=1000, MAXRUN=2000, EPS=.000001)
REAL*4 UNIRV(15,1000),TEMP(1000),QI(KK),AI(KK),AHATI(KK)
REAL*4 QHATI(KK),NMAX,NNMAX,QHTMAX,CHISQR(5,5),ALFA(MAXALF)
REAL*4 DF(5),AALFA(5),SUMNAI,RSHAT(MAXALF,MAXREP),RS
REAL*4 KEY1(MAXREP),KEY2(MAXREP),KEY3(MAXREP),TRNSTR(MAXREP)
REAL*4 DEGFR(MAXREP),QHTUPR(MAXALF,MAXREP),CHISQ(MAXALF,MAXREP)
REAL*4 QUPA1(MAXREP),QUPA2(MAXREP),RHTSTR(MAXALF,MAXREP)
REAL*4 DELTAR(MAXALF),TRANSQ(MAXREP),TRANSR(MAXREP),DIFF(MAXREP)
REAL*4 DELSTR(MAXALF),NIMIN,NIMAX,NIREAL(KK)
REAL*4 RSHTBR(MAXALF,MAXREP),DELBGR(MAXALF),KEY4(MAXREP)
REAL*4 TRANBR(MAXREP),RSBRDG,MSTRQ
REAL*4 ZFPREP

```

```

INTEGER SEED,MULT,SORT,TRIALS(15,1000),BIGF,FI(KK),N(KK)
INTEGER NINDX,QINDX,ERROR,REPS,SELCTA,SELCTK,TOTREP
INTEGER C1C15,REPSHD,SELCTB,ALF,FLAG,LOOP,PRNT

```

```

INTEGER QUANTL(MAXALF), TRUQNT(MAXALF), ZFAILS, FAILS, INC

DATA SEED/123457/, MULT/1/, INC/1/
DATA AALFA/.01,.05,.9,.95,.99/, DF/1,5,10,30,40/
DATA ALFA/.20,.050/
DATA SORT/0/

ASSIGN 8 TO C1C15
ASSIGN 9 TO REPSHD

* CALL COMPRS
  PRNT = NPRNT

DO 12 I=1, KK
  AI(I) = 9999.
  N(I) = 99999999
12 CONTINUE

  READ(03,*) K, MSTRQ

DO 11 I=1, K
  READ(03,*) AI(I), N(I)
11 CONTINUE

  IF(K.NE.5) THEN
    WRITE(1,('WARNING: BRIDGE STRUCTURE ',
+ 'ONLY USES THE FIRST 5 COMPONENTS'))
  ELSE
    END IF

***// INITIALIZE THE QHTUPR ARRAY OF UNRELIABILITY REPLICATIONS, //***
* RSHAT ARRAY OF ESTIMATE SYSTEM RELIABILITY REPLICATIONS *
* AND RHTSTR ARRAY OF EST. SYST. REL. FOR A SERIES SYST WHEN *
***// ALL THE COMPONENT MISSION TESTS ARE EQUAL IN NUMBER //***

DO 172 ALF=1, MAXALF
DO 173 REPS=1, MAXREP
  QHTUPR(ALF, REPS) = 0.
  RSHAT(ALF, REPS) = 0.
  RHTSTR(ALF, REPS) = 0.
  RSHTBR(ALF, REPS) = 0.
173 CONTINUE
172 CONTINUE

***// SET FLAG TO 1 IF ALL COMPONENTS HAVE SAME NO. OF MISSION TESTS***

FLAG=1
DO 50 I=1, K -1
  IF((N(I) - N(I+1)).NE.0) THEN
    FLAG=0
  ELSE
    END IF
50 CONTINUE
PRINT *, 'FLAG IS:', FLAG
***// MAIN PROGRAM OUTER LOOP START(EVERY LOOP IS ONE REPLICATION)***

```

```

ZFPREP = 0.
ZFAILS = 0
FAILS = 0
TOTREP = 0
LOOP = 0
10 IF(LOOP.LT.MAXREP) THEN
    LOOP = LOOP + 1
    IF(TOTREP.LT.MAXRUN) THEN
        TOTREP = TOTREP + 1
    SELCTA = 1
    SELCTB = 2
***// FILL ARRAY KEY(REPS) WITH INTEGERS 1 TO K TO BE USED AS OUTPUT
***// OF THE SUBROUTINE SHSORT
    DO 95 REPS=1, MAXREP
        KEY1(REPS) = REPS
        KEY2(REPS) = REPS
        KEY3(REPS) = REPS
        KEY4(REPS) = REPS
    95 CONTINUE

***// CALCULATE NMAX NOT TO PRINT LONGER THAN THE MAX SAMPLE SIZE
***// CALCULATE THE MAXIMUM NO. OF TRIALS AND ITS INDEX NO. /***

    CALL IMAX(N,K,NMAX,NINDX)

***// CALCULATE THE QI'S FROM THE GIVEN MASTER Q AND THE AI'S
    DO 115 I=1, K
        QI(I) = MSTRQ * AI(I)
    115 CONTINUE

    DO 120 I=1,15
        DO 125 J=1,500
            UNIRV(I,J) = 999.
            TRIALS(I,J) = 99999
        125 CONTINUE
    120 CONTINUE

***// DRAW UNIFORM (0,1) RV'S AND CONVERT TO BERNOULLI TRIALS /***
    DO 130 I=1, K
        CALL SRND(SEED, TEMP, N(I), MULT, SORT)
        DO 135 J=1, N(I)
            UNIRV(I,J) = TEMP(J)
            IF (UNIRV(I,J).LE. 1 - QI(I)) THEN
                TRIALS(I,J) = 0
            ELSE
                TRIALS(I,J) = 1
            END IF
        135 CONTINUE
    130 CONTINUE

```

// CALCULATE THE NO. OF FAILURES FOR EACH COMPONENT //

```

DO 150 I=1, K
  FI(I) = 0
150 CONTINUE

```

***// CALCULATE THE F SUB I'S AND THE GRAND TOTAL NO. OF FAILURES

```

BIGF = 0
DO 155 I=1, K
  DO 160 J=1, N(I)
    FI(I) = FI(I) + TRIALS(I,J)
160 CONTINUE
    IF(FI(I).EQ.0) THEN
      ZFPREP = ZFPREP + 1
    ELSE
      END IF

```

***// CALCULATE THE QHAT SUB I'S: F SUB I'S DIVIDED BY N SUB I'S

```

  QHATI(I) = REAL(FI(I)) / N(I)
  BIGF = BIGF + FI(I)
155 CONTINUE

```

***// CASE WHERE NO COMPONENTS HAVE ANY FAILURES

//***

```

  IF(BIGF.EQ.0) THEN
    ZFAILS = ZFAILS + 1
    DO 200 I=1, K
      NIREAL(I) = REAL(N(I))
200 CONTINUE
      CALL USMNMX(NIREAL,K,INC,NIMIN,NIMAX)
      DO 205 ALF=1, MAXALF
        CALL MDCHI(1 - ALFA(ALF),2.,CHISQ(ALF,LOOP),ERROR)
        RSHAT(ALF,LOOP)= 1 - (CHISQ(ALF,LOOP) / REAL(2 * NIMIN))
        IF(FLAG.EQ.1) THEN
          RHTSTR(ALF,LOOP)=1-(CHISQ(ALF,LOOP) / REAL(2 * N(1)))
        ELSE
          END IF
205 CONTINUE
        IF(PRNT.EQ.1) THEN
          WRITE(1,0007)
          WRITE(1,C1C15)
          WRITE(1,3334) QI
          WRITE(1,0001)
          WRITE(1,C1C15)
          DO 141 J=1,NMAX
            WRITE(1,1111) (UNIRV(I,J), I=1, K)
141 CONTINUE
            WRITE(1,0002)
            WRITE(1,C1C15)
            DO 146 J=1,NMAX
              WRITE(1,2222) (TRIALS(I,J), I=1, K)
146 CONTINUE
            WRITE(1,0003)
            WRITE(1,C1C15)
            WRITE(1,3333) FI
            WRITE(1,0005)
            WRITE(1,C1C15)

```



```

        WRITE(1,3335) N
        WRITE(1,0004)
        WRITE(1,C1C15)
        WRITE(1,3334) QHATI
WRITE(1,('/'THE MAXIMUM Q HAT SUB I IS:', T40, F8.5')) QHTMAX
WRITE(1,('/'THE MAXI Q HAT SUB I IS ELMNT NO.:', T40, I5')) QINDX
WRITE(1,('/'THE GRAND TOTAL NO. OF FAILURES IS:', T40, I5')) BIGF
ELSE
ENDIF

        DEGFR(LOOP) = 2.
        GO TO 10

ELSE
        FAILS = FAILS + 1
END IF

***// FIND THE MAX OF THE INDIVIDUAL COMPONENT UNRELIABILITIES
CALL RMAX(QHATI, K, QHTMAX, QINDX)

***// PRINT THE RESULT OF THE MAIN OPERATING ELEMENTS OF THE PROGRAM

        IF(PRNT.EQ.1) THEN
                WRITE(1,0007)
                WRITE(1,C1C15)
                WRITE(1,3334) QI
                WRITE(1,0001)
                WRITE(1,C1C15)
                DO 140 J=1,NMAX
                        WRITE(1,1111) (UNIRV(I,J), I=1, K)
140          CONTINUE
                WRITE(1,0002)
                WRITE(1,C1C15)
                DO 145 J=1,NMAX
                        WRITE(1,2222) (TRIALS(I,J), I=1, K)
145          CONTINUE
                WRITE(1,0003)
                WRITE(1,C1C15)
                WRITE(1,3333) FI
                WRITE(1,0005)
                WRITE(1,C1C15)
                WRITE(1,3335) N
                WRITE(1,0004)
                WRITE(1,C1C15)
                WRITE(1,3334) QHATI
WRITE(1,('/'THE MAXIMUM Q HAT SUB I IS:', T40, F8.5')) QHTMAX
WRITE(1,('/'THE MAXI Q HAT SUB I IS ELMNT NO.:', T40, I5')) QINDX
WRITE(1,('/'THE GRAND TOTAL NO. OF FAILURES IS:', T40, I5')) BIGF
ELSE
ENDIF

***// CALCULATE THE AHAT SUB I'S (WEIGHT ESTIMATES)

        SUMNAI = 0.
        DO 165 I=1, K
                AHATI(I) = QHATI(I) / QHTMAX
                SUMNAI = SUMNAI + N(I) * AHATI(I)
165      CONTINUE

```

```

IF(PRNT.EQ.1) THEN
    WRITE(1,0006)
    WRITE(1,C1C15)
    WRITE(1,3334) AHATI
ELSE
END IF

***// CALCULATE 1 REPLICATION OF UPPR ALFA C.L. ON SYSTEM RELIABILITY

DEGFR(LOOP) = 2 * (1 + BIGF)

DO 170 ALF=1, MAXALF
    CALL MDCHI(1 - ALFA(ALF),DEGFR(LOOP),CHISQ(ALF,LOOP), ERROR)
    QHTUPR(ALF,LOOP) = CHISQ(ALF,LOOP) / (2 * SUMNAI)
    IF(FLAG.EQ.1) THEN
        RHTSTR(ALF,LOOP) = 1 -(CHISQ(ALF,LOOP) / REAL(2*N(1)))
    ELSE
    END IF
*   + (ALF,LOOP), ALFA(ALF)
***// CALCULATE VALUE OF THE SYSTEM RELIABILITY FOR COMPNTS. IN SERIES

    CALL RHTSRS(QHTUPR(ALF,LOOP), AHATI,K, RSHAT(ALF,LOOP))
*   +T40,F8.5') RSHAT(ALF,LOOP)

***// CALCULATE VALUE OF THE SYSTEM RELIABILITY FOR BRIDGE STRUCTURE ***

    CALL RHTBRG(QHTUPR(ALF,LOOP),AHATI,K,RSHTBR(ALF,LOOP))
170 CONTINUE

***// THIS ELSE AND ENDIF ARE FOR THE TEST AGAINST MAXRUN *****
ELSE
    WRITE(1,(' ',' '),'PROGRAM EXCEEDED THE MAX NO. OF RUNS',
+ ' ALLOWED OF: ',I6) TOTREP
    GOTO 9999

END IF
GOTO 10
END IF

***// SORT THE ARRAYS OF SYSTEM UNRELIABILITIES(1 FOR EACH CONF. LEVEL)

DO 700 ALF=1, MAXALF
    DO 800 REPS=1, MAXREP
        TRANSQ(REPS) = QHTUPR(ALF,REPS)
        TRANSR(REPS) = RSHAT(ALF,REPS)
        TRNSTR(REPS) = RHTSTR(ALF,REPS)
        TRANBR(REPS) = RSHTBR(ALF,REPS)
800 CONTINUE
    CALL SHSORT(TRANSQ,KEY1,MAXREP)
    CALL SHSORT(TRANSR,KEY2,MAXREP)
    CALL SHSORT(TRNSTR,KEY3,MAXREP)
    CALL SHSORT(TRANBR,KEY4,MAXREP)
    DO 900 REPS=1, MAXREP
        QHTUPR(ALF,REPS) = TRANSQ(REPS)
        RSHAT(ALF,REPS) = TRANSR(REPS)
        RHTSTR(ALF,REPS) = TRNSTR(REPS)

```

```

          RSHTBR(ALF,REPS) = TRANBR(REPS)
900      CONTINUE
700      CONTINUE

```

// PRINT OUTPUT REPORT HEADINGS **

```

WRITE(1,6666)
WRITE(1,6667) MAXREP
WRITE(1,6668) K
WRITE(1,6669)
IF(K.EQ.5) THEN
    WRITE(1,6699)
ELSE
END IF
WRITE(1,6670) MSTRQ
WRITE(1,6671)
WRITE(1,C1C15)
WRITE(1,3334) AI
WRITE(1,0007)
WRITE(1,C1C15)
WRITE(1,3334) QI
WRITE(1,0005)
WRITE(1,C1C15)
WRITE(1,3335) N
WRITE(1,6674)
WRITE(2,6666)
WRITE(2,6667) MAXREP
WRITE(2,6668) K
WRITE(2,6669)
IF(K.EQ.5) THEN
    WRITE(1,6699)
ELSE
END IF
WRITE(2,6670) MSTRQ
WRITE(2,6671)
WRITE(2,C1C15)
WRITE(2,3334) AI
WRITE(2,0007)
WRITE(2,C1C15)
WRITE(2,3334) QI
WRITE(2,0005)
WRITE(2,C1C15)
WRITE(2,3335) N
WRITE(2,6674)

WRITE(2,(''SORTED RSHAT 1 IS:'',/10(F8.5))')
+(RSHAT(1,REPS), REPS=1, MAXREP)
WRITE(2,(''SORTED RSHAT 2 IS:'',/10(F8.5))')
+(RSHAT(2,REPS), REPS=1, MAXREP)
IF(FLAG.EQ.1) THEN
    WRITE(2,(''SORTED RHTSTR 1 IS:'',/10(F8.5))')
+(RHTSTR(1,REPS), REPS=1, MAXREP)
    WRITE(2,(''SORTED RHTSTR 2 IS:'',/10(F8.5))')
+(RHTSTR(2,REPS), REPS=1, MAXREP)
ELSE

```



```

WRITE(1,6676)
DO 400 ALF=1,MAXALF
  TRUQNT(ALF) = 0
  DO 500 REPS=1, MAXREP
    DIFF(REPS) = RS - RSHAT(ALF,REPS)
500  CONTINUE
    DO 600 REPS=1, MAXREP
      IF(ABS(DIFF(REPS)).LE.EPS) THEN
        TRUQNT(ALF) = REPS
        WRITE(1,(' ','',/'TRUE CONFIDENCE LIMIT IS:','
+      F8.4)')
+      (TRUQNT(ALF) / REAL(MAXREP)) * 100.
        GO TO 620
      ELSEIF(DIFF(REPS).LT.0.) THEN
        TRUQNT(ALF) = REPS
        GO TO 610
      ELSE
        END IF
600  CONTINUE
610  IF(TRUQNT(ALF).EQ.0.) THEN
        WRITE(1,4443) ALFA(ALF)
        WRITE(1,(' ','',/'THE SMALLEST',
+      '' DIFFERENCE BETWEEN RS AND RSHAT IS: ','F10.5)') DIFF(
+      MAXREP)
        ELSEIF(TRUQNT(ALF).EQ.1.) THEN
        WRITE(1,4442) ALFA(ALF)
        WRITE(1,(' ','',/'ALL RSHAT',
+      '' ARE GREATER THAN RS''))
        ELSEIF(ABS(DIFF(TRUQNT(ALF))).LE.ABS(DIFF(TRUQNT(ALF) - 1)))
+      THEN
        WRITE(1,4444) ALFA(ALF),
+      (TRUQNT(ALF) / REAL(MAXREP)) * 100.
        WRITE(1,4445) RSHAT(ALF,TRUQNT(ALF))
        WRITE(1,4446)
        ELSE
        WRITE(1,4444) ALFA(ALF),
+      ((TRUQNT(ALF)-1) / REAL(MAXREP)) * 100.
        WRITE(1,4445) RSHAT(ALF,TRUQNT(ALF)-1)
        WRITE(1,4447)
620  END IF
400  CONTINUE

```

```

***// FIND THE TRUE CONFIDENCE LEVEL OF THE SYSTEM REL. ESTIMATE //***
***// ***** RSHTBR (BRIDGE) ***** //***

```

```

IF(K.EQ.5) THEN
DO 401 ALF=1,MAXALF
  TRUQNT(ALF) = 0
  DO 501 REPS=1, MAXREP
    DIFF(REPS) = RSBRDG - RSHTBR(ALF,REPS)
501  CONTINUE
    DO 601 REPS=1, MAXREP
      IF(ABS(DIFF(REPS)).LE.EPS) THEN
        TRUQNT(ALF) = REPS
        - WRITE(1,(' ','',/'TRUE CONFIDENCE LIMIT IS:','

```

```

+      F8.4)')
+      (TRUQNT(ALF) / REAL(MAXREP)) * 100.
      GO TO 621
      ELSEIF(DIFF(REPS).LT.0.) THEN
      TRUQNT(ALF) = REPS
      GO TO 611
      ELSE
      END IF
601    CONTINUE
611    IF(TRUQNT(ALF).EQ.0.) THEN
      WRITE(1,4443) ALFA(ALF)
      WRITE(1,(' ','',/'THE SMALLEST',
+      '' DIFFERENCE BETWEEN RSBRDG AND RSHTBR IS:',
+      F10.5)-) DIFF(MAXREP)
      ELSEIF(TRUQNT(ALF).EQ.1.) THEN
      WRITE(1,4442) ALFA(ALF)
      WRITE(1,(' ','',/'ALL RSHTBR',
+      '' ARE GREATER THAN RSBRDG'))')
      ELSEIF(ABS(DIFF(TRUQNT(ALF))).LE.ABS(DIFF(TRUQNT(ALF) - 1)))
+      THEN
      WRITE(1,4444) ALFA(ALF),
+      (TRUQNT(ALF) / REAL(MAXREP)) * 100.
      WRITE(1,4449) RSHTBR(ALF,TRUQNT(ALF))
      WRITE(1,4446)
      ELSE
+      WRITE(1,4444) ALFA(ALF),
+      ((TRUQNT(ALF)-1) / REAL(MAXREP)) * 100.
      WRITE(1,4449) RSHTBR(ALF,TRUQNT(ALF)-1)
      WRITE(1,4447)
621    END IF
401    CONTINUE
      ELSE
      END IF

```

```

***// FIND THE TRUE CONFIDENCE LEVEL OF THE SYSTEM REL. ESTIMATE //***
***//          ***** RHTSTR *****          //***

```

```

      IF(FLAG.EQ.1) THEN
      DO 4400 ALF=1,MAXALF
      TRUQNT(ALF) = 0
      DO 5500 REPS=1, MAXREP
      DIFF(REPS) = RS - RHTSTR(ALF,REPS)
5500    CONTINUE
      DO 6600 REPS=1, MAXREP
      IF(ABS(DIFF(REPS)).LE.EPS) THEN
      TRUQNT(ALF) = REPS
      WRITE(1,(' ','',/'TRUE CONFIDENCE LIMIT IS:',
+      F8.4)')
+      (TRUQNT(ALF) / REAL(MAXREP)) * 100.
      GO TO 6620
      ELSEIF(DIFF(REPS).LT.0.) THEN
      TRUQNT(ALF) = REPS
      GO TO 6610
      ELSE
      END IF

```

```

6600      CONTINUE
6610      IF(STRUQNT(ALF).EQ.0.) THEN
           WRITE(1,4443) ALFA(ALF)
           WRITE(1,(' ','',/'THE SMALLEST',
+           ' ' DIFFERENCE BETWEEN RS AND RHTSTR IS: ',
+           F9.5)') DIFF(MAXREP)
           ELSEIF(STRUQNT(ALF).EQ.1.) THEN
           WRITE(1,4442) ALFA(ALF)
           WRITE(1,(' ','',/'ALL RHTSTR',
+           ' ' ARE GREATER THAN RS')')
           ELSEIF(ABS(DIFF(STRUQNT(ALF))).LE.ABS(DIFF(STRUQNT(ALF) - 1)))
+           THEN
           WRITE(1,4444) ALFA(ALF),
+           (STRUQNT(ALF) / REAL(MAXREP)) * 100.
           WRITE(1,4448) RHTSTR(ALF,STRUQNT(ALF))
           WRITE(1,4446)
           ELSE
+           WRITE(1,4444) ALFA(ALF),
           ((STRUQNT(ALF)-1) / REAL(MAXREP)) * 100.
           WRITE(1,4448) RHTSTR(ALF,STRUQNT(ALF)-1)
           WRITE(1,4447)
6620      END IF
4400      CONTINUE
           ELSE
           END IF

```

// PRINT THE ARRAYS PERTINENT TO THE OUPUT OF EACH REPLICATION **

```

           IF(PRNT.EQ.1) THEN
           I = 1
185      WRITE(1,REPSHD) ALFA(SELCTA), ALFA(SELCTA),
+ALFA(SELCTB),ALFA(SELCTB),ALFA(SELCTA),ALFA(SELCTA),ALFA(SELCTB),
+ALFA(SELCTB)
175      IF(I.GE.(MAXREP + 1)) THEN
           GOTO 180
           ELSE
           IF( (I.EQ.71).OR.(I.EQ.211).OR.(I.EQ.351).OR.(I.EQ.491).OR.
+           (I.EQ.631).OR.(I.EQ.771).OR.(I.EQ.911).OR.(I.EQ.1051) ) THEN
           I = I + 70
           WRITE(1,(' '+''))
           GOTO 185
           ELSE
           WRITE(1,3336) I, INT(DEGFR(I)), CHISQ(1,I), QHTUPR(1,I),
+           CHISQ(2,I), QHTUPR(2,I)
           END IF
           IF(I + 70.LE.MAXREP) THEN
           WRITE(1,3337) I+70, INT(DEGFR(I+70)),CHISQ(1,I+70),
+           QHTUPR(1,I+70),CHISQ(2,I+70),QHTUPR(2,I+70)
           ELSE
           END IF
           I = I + 1
           GOTO 175
180      END IF
           ELSE
           ENDIF

```

```

9999 WRITE(1,('THE TOTAL NO OF REPS WAS:',I8)) TOTREP
      WRITE(1,('THE TOTAL NO OF EFFECTIVE REPS WAS:',I8)) LOOP
      WRITE(1,('THE TOTAL NO OF NO FAILURE RUNS WAS:',I8)) ZFAILS
      WRITE(1,('AVERAGE NO. OF COMPONENTS PER REPLICATION WITH ',
+ 'NO FAILURES:',F5.2)) ZFPREP / MAXREP
      WRITE(1,('THE TOTAL NO OF RUNS WITH FAILURES WAS:',I8)) FAILS
0008 FORMAT (/ 3X,'C 1',5X,'C 2',
+5X,'C 3',5X,'C 4',5X,'C 5',5X,'C 6',5X,'C 7',5X,
+ 'C 8',5X,'C 9',5X,'C 10',4X,'C 11',4X,
+ 'C 12',4X,'C 13',4X,'C 14',4X,'C 15')
0009 FORMAT(/1X,'REP NO',2X,'DF',1X,'CHISQR(',F4.3,')',1X,
+ 'QHTUPR(',F4.3,')',1X,'CHISQR(',F4.3,')',1X,'QHTUPR(',F4.3,')',
+ 2X,'REP NO',2X,'DF',1X,'CHISQR(',F4.3,')',1X,
+ 'QHTUPR(',F4.3,')',1X,'CHISQR(',F4.3,')',1X,'QHTUPR(',F4.3,')'/)
0001 FORMAT (///'UNIFORM RANDOM DEVIATES ARE:')
0002 FORMAT (///'BERNOULLI TRIALS ARE:')
0003 FORMAT (///'TOTAL NO. OF FAILURES FOR EACH COMPONENT:')
0004 FORMAT (///'ESTIMATED UNRELIABILITY FOR EACH COMPONENT:')
0005 FORMAT (///'TOTAL NUMBER OF MISSION TESTS:')
0006 FORMAT (///'ESTIMATED WEIGHTS FOR EACH COMPONENT:')
0007 FORMAT (///'Q I FOR EACH COMPONENT:')
1111 FORMAT (15F8.5)

2222 FORMAT (/1X,15(I4,4X))
3333 FORMAT (/1X,15(I4,4X))
3334 FORMAT (/15F8.5)
3335 FORMAT (/1X,15(I4,4X))
3336 FORMAT (T3,I4,T9,I3,T13,F11.5,T27,F8.5,T39,F11.5,T53,F8.5)
3337 FORMAT ('+',T67,I4,T73,I3,T77,F11.5,T91,F8.5,T103,F11.5,T117,F8.5)
4442 FORMAT (' ',///'THE RESULTING (1 - ',F4.3,') CONFIDENCE ',
+ 'LIMIT IS:',T50,' 00.000 ')
4443 FORMAT (' ',///'THE RESULTING (1 - ',F4.3,') CONFIDENCE ',
+ 'LIMIT IS:',T50,' 100.0000 ')
4444 FORMAT (' ',///'THE RESULTING (1 - ',F4.3,') CONFIDENCE ',
+ 'LIMIT IS:',T50,F8.4)
4445 FORMAT (' ',/'THE RSHAT VALUE CLOSEST TO RS IS: ',T51,F8.5)
4446 FORMAT (' ',/'(FIRST NEGATIVE DIFFERENCE)')
4447 FORMAT (' ',/'(ELEMENT PRECEEDING FIRST NEGATIVE DIFFERENCE)')
4448 FORMAT (' ',/'THE RHTSTR VALUE CLOSEST TO RS IS: ',T51,F8.5)
4449 FORMAT (' ',/'THE RSHTBR VALUE CLOSEST TO RSBRDG IS: ',T51,F8.5)
5555 FORMAT (' ',///'THE ',I4,'(1-',F4.3,') QUANTILE IS:',T49,F8.3)
5556 FORMAT (' ',/'THE VALUE OF RSHAT FOR THAT QUANTILE IS:',T51,F8.5)
5557 FORMAT (' ',/'THE DIFFERENCE(RS - RSHAT) IS:',T51,F8.5)
5656 FORMAT (' ',/'THE VALUE OF RHTSTR FOR THAT QUANTILE IS:',T51,F8.5)
5666 FORMAT (' ',/'THE VALUE OF RSHTBR FOR THAT QUANTILE IS:',T51,F8.5)
5657 FORMAT (' ',/'THE DIFFERENCE(RS - RHTSTR) IS:',T51,F8.5)
5667 FORMAT (' ',/'THE DIFFERENCE(RS - RSHTBR) IS:',T51,F8.5)
5755 FORMAT (' ',///'SINCE THE NO. OF MISSION TESTS IS THE SAME FOR',
+ ' ALL COMPONENTS THE CLOSED FORM SERIES SYSTEM RELIABILITY ',
+ ''RHTSTR' IS COMPUTED')
6666 FORMAT ('+', '*****',
+ '***** RUN INPUT SETTINGS *****',
+ '*****')
6667 FORMAT (' ',/'NUMBER OF REPLICATIONS:',T50,I4)
6668 FORMAT (' ',/'NUMBER OF COMPONENTS:',T50,I4)
6669 FORMAT (' ',/'SYSTEM RELIABILITY FUNCTION:',T50,'SERIES')

```



```

6699 FORMAT (' ',///'SYSTEM RELIABILITY FUNCTION: ',T50,'BRIDGE')
6670 FORMAT (' ',///'MASTER UNRELIABILITY USED: ',T50,F8.5)
6671 FORMAT (' ',///'INPUT WEIGHTS(A SUB I'S): ')
6674 FORMAT ('+',///'*****',
+ '***R U N   R E S U L T S*****',
+ '*****')
6675 FORMAT ('+',///'*****',
+ ' ESTIMATE ERRORS *****',
+ '*****')
6676 FORMAT ('+',///'*****',
+ ' TRUE CONFIDENCE LIMITS *****',
+ '*****')
END

```

APPENDIX B. INTERVAL ESTIMATING PROCEDURE 2

PROGRAM ZFNCSY

```

*****
*
*      TITLE: BINOMIAL INTERVAL ESTIMATION PROCEDURE
*              ZERO FAILURES DISALLOWED; WITH SCALING
*      AUTHOR: E. F. BELLINI, LT, USN
*              DATE: NOV 89
*
*      THIS PROGRAM COMPUTES THE TRUE CONFIDENCE LEVEL FOR THE ESTIMATE
*      RELIABILITY OF A SERIES AND BRIDGE SYSTEM GIVEN THE RELIABILITY
*      OF THEIR COMPONENTS
*
*      IN ITS PRESENT CONFIGURATION THIS PROGRAM IS SET UP TO RUN 12
*      TIMES EACH TIME PRODUCING 1000 REPLICATIONS USING A DIFFERENT
*      SET OF INPUT DATA.  RUN THE PROGRAM FROM CMS BY TYPING 'B1 EXEC'.
*      THE REXX EXEC PROGRAM
*      'B1' CALLS THE INPUT FILES TO BE READ AND NAMES THE 12 OUTPUT
*      FILES RESULTING FROM THE 12 CONSECUTIVE RUNS.  BY EDITING THE
*      INDEX COUNTERS I, J, K OF THE 'B1' EXEC ONE CAN RUN ANY USER-
*      SPECIFIC RUN FROM JUST ONE RUN TO ALL 12.
*
*      VARIABLES USED
*
*      AHATI : WEIGHT ESTIMATES FOR EACH COMPONENT
*      AI    : INPUT WEIGHTS FOR EACH COMPONENT
*      ALFA  : LEVELS OF SIGNIFICANCE
*      BIGF  : TOTAL NO. OF FAILURES FOR EACH REPLICATION
*      CHISQ : CHI-SQUARE RANDOM VARIABLE VALUE
*      COUNT1 : COUNTS THE NO. OF COMPONENTS WITH FAILURES
*      C1C15 : FORMAT LABEL
*      DEGFR : DEGREES OF FREEDOM
*      DELBRG : DIFFERENCE FOR BRIDGE SYSTEM
*      DELSTR : DIFFERENCE FOR SERIES SYSTEM- CLOSED FORM
*      DELTAR : DIFFERENCE FOR SERIES SYSTEM
*      DIFF  : DIFFERENCE (TRUE REL. - ESTIMATED REL.)
*      EPS   : SMALL QUANTITY(CONSTANT)
*      ERROR : PARAMETER FOR IMSL ROUTINE
*      FAILS : COUNTS NO. OF REPLICATIONS WITH AT LST. 1 FAILURE
*      FI    : NO. OF FAILURES FOR EACH COMPONENT(ALL MISSION TST)
*      FLAG  : 1 IF ALL COMP. HAVE SAME NO. OF MISSION TESTS
*      INC   : INCREMENT STEP SIZE FOR ROUTINE USMNMX
*      KEY1  : ARRAY OF INDECS FOR ROUTINE SHSORT
*      KEY2  : ARRAY OF INDECS FOR ROUTINE SHSORT
*      KEY3  : ARRAY OF INDECS FOR ROUTINE SHSORT
*      KEY4  : ARRAY OF INDECS FOR ROUTINE SHSORT
*      KK    : ARRAY SIZING PARAMETER FOR THE MAX NO OF COMPONENTS
*      LOOP  : COUNTS NO. OF REPLICATION PERFORMED
*      MAXALF : MAX NO. OF SIGNIFICANT LEVELS DESIRED(ARRAY SIZING)
*      MAXREP : MAX NO. OF REPLICATIONS
*      MAXRUN : MAX NO. OF PROGRAM ITERATIONS ALLOWED
*      MSTRQ : MASTER UNRELIABILITY(USED WITH AI'S TO CALC. QI'S)

```

```

*      MULT   : MULTIPLIER FOR RANDOM NO. GENERATOR SRND      *
*      N      : NO. OF MISSION TEST FOR EACH COMPONENT        *
*      NIMAX  : MAX NO. OF MISSION TESTS                      *
*      NIMIM  : MIN NO. OF MISSION TESTS                      *
*      NINDX  : INDEX NO. OF MAX NO. OF MISSION TESTS        *
*      NIREAL : NO. OF MISSION TESTS TRANSFORMED TO REAL      *
*      NMAX   : MAX NO. OF MISSION TESTS FOR OUTPUT CONTROL   *
*      NPRNT  : FLAG FOR DETAILED REPORT OUTPUT               *
*      PRNT   : SAME AS ABOVE(PARAMETER)                      *
*      QHATI  : UNRELIABILITY ESTIMATES FOR EACH COMPONENT    *
*      QHTMAX : LARGEST QHATI                                  *
*      QHTUPR : UPPER LIMIT ON SYSTEM UNRELIABILITY          *
*      QI     : INPUT UNRELIABILITY FOR EACH COMPONENT        *
*      QINDX  : INDEX                                          *
*      QUANTL : QUANTILE                                       *
*      REPSHD : REPLICATIONS HEADING FORMAT NUMBER           *
*      RHTSTR : SERIES SYSTEM RELIABILITY ESTIMATE(CLOSED FORM)
*      RS     : TRUE SERIES SYSTEM RELIABILITY                *
*      RSBRDG : TRUE BRIDGE SYSTEM RELIABILITY               *
*      RSHAT  : SERIES SYSTEM RELIABILITY ESTIMATE            *
*      RSHTBR : BRIDGE SYSTEM RELIABILITY ESTIMATE            *
*      SEED   : PARAMETER                                      *
*      SELCTA : SIGNIFICANCE LEVEL SELECTION                  *
*      SELCTB : SIGNIFICANCE LEVEL SELECTION                  *
*      SORT   : PARAMETER FOR ROUTINE SRND                    *
*      SUMNAI : SUM OF THE PRODUCT OF NI'S AND AI'S           *
*      TEMP   : TEMPORARY ARRAY                                *
*      TOTREP : TOTAL NUMBER OF PROGRAM ITERATIONS            *
*      TRANBR : TEMPORARY ARRAY                                *
*      TRANSQ : TEMPORARY ARRAY                                *
*      TRANSR : TEMPORARY ARRAY                                *
*      TRIALS : BERNOULLI TRIALS ARRAY (2-DIM)                 *
*      TRNSTR : TEMPORARY ARRAY                                *
*      TRUQNT : TRUE QUANTILE                                   *
*      UNIRV  : UNIFORM RANDOM DEVIATES (2-DIM)               *
*      ZFAILS : TOTAL NUMBER OF REPLICATIONS WITH ZERO FAILURES
*      ZFPREP : NO. OF COMPTS. WITH ZERO FAILURES PER REPLICATION
*
*****

```

```

PARAMETER (KK=10,MAXALF=2,NPRNT=0)
PARAMETER (MAXREP=1000, MAXRUN=10000, EPS=.000001)

```

```

REAL*4 UNIRV(15,1000),TEMP(1000),QI(KK), AI(KK), AHATI(KK)
REAL*4 QHATI(KK), NMAX, QHTMAX, ALFA(MAXALF)
REAL*4 DF(5),AALFA(5),SUMNAI,RSHAT(MAXALF,MAXREP),RS
REAL*4 KEY1(MAXREP),KEY2(MAXREP),KEY3(MAXREP),TRNSTR(MAXREP)
REAL*4 DEGFR(MAXREP), QHTUPR(MAXALF,MAXREP),CHISQ(MAXALF,MAXREP)
REAL*4 RHTSTR(MAXALF,MAXREP)
REAL*4 DELTAR(MAXALF), TRANSQ(MAXREP),TRANSR(MAXREP),DIFF(MAXREP)
REAL*4 DELSTR(MAXALF), NN(KK)
REAL*4 RSHTBR(MAXALF,MAXREP),DELBGR(MAXALF),KEY4(MAXREP)
REAL*4 TRANBR(MAXREP), RSBRDG
REAL*4 SCALEN, MINQI, MAXQI, ZFPREP,MSTRQ

```

```

INTEGER SEED, MULT, SORT, TRIALS(15,1000), BIGF, FI(KK), N(KK)

```

```

INTEGER NINDX, QINDX, ERROR, REPS, SELCTA, SELCTQ, TOTREP
INTEGER COUNT1, C1C15, REPSHD, SELCTB, ALF, FLAG, LOOP, PRNT
INTEGER QUANTL(MAXALF), TRUQNT(MAXALF), ZFAILS, FAILS
INTEGER INC

```

```

DATA SEED/123457/, MULT/1/, INC/1/
DATA AALFA/.01,.05,.9,.95,.99/, DF/1,5,10,30,40/
DATA ALFA/.20,.050/
* DATA MSTRQ/0.1,.05/
* DATA AI/.20,.10,.05,.05,.05/
* DATA AI/.20,.10,.05,.05,.05,.05,.05,.05,.05,.05/
* DATA AI/.05,.05,.05,.05,.05,.05,.05,.05,.05,.05/
* DATA AI/.05,.05,.05,.05,.05,.05,.05,.05,.05,.05,.05,.05,
* +.05,.05/
* DATA AI/.1,.1,.1,.1,.05,.05,.2,.25,.5/
* DATA AI/.1,.1,.1,.05,.2/
* DATA N/100,100,100,100,100/
* DATA N/10,6,5,2,10,4,5,6,7,2/
* DATA N/50,50,50,50,50,50,50,50,50,50/
* DATA N/100,100,100,100,100,100,100,100,100,100/
* DATA N/300,300,300,300,300,300,300,300,300,300/
* DATA N/20,20,20,20,20,20,20,20,20,20/
* DATA N/1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,
* +1000,1000,1000,1000/
DATA SORT/0/

```

```

ASSIGN 8 TO C1C15
ASSIGN 9 TO REPSHD

```

```

* CALL EXCMS('FILEDEF 01 DISK B OUTPUT A1 (LRECL 132 ')
* CALL EXCMS('FILEDEF 02 DISK JNK OUTPUT A1 (LRECL 132 ')

```

```

SELCTQ = 1
PRNT = NPRNT

```

```

DO 12 I=1,KK
    AI(I) = 9999.
    N(I) = 99999999
12 CONTINUE
    READ(03,*)K,MSTRQ

```

```

    DO 11 I=1,K
        READ(03,*) AI(I),N(I)
11 CONTINUE

```

```

****// INITIALIZE THE QHTUPR ARRAY OF UNRELIABILITY REPLICATIONS, //***
* RSHAT ARRAY OF ESTIMATE SYSTEM RELIABILITY REPLICATIONS *
* AND RHTSTR ARRAY OF EST. SYST. REL. FOR A SERIES SYST WHEN *
****// ALL THE COMPONENT MISSION TESTS ARE EQUAL IN NUMBER //***

```

```

DO 172 ALF=1,MAXALF
    DO 173 REPS=1,MAXREP
        QHTUPR(ALF,REPS) = 0.
        RSHAT(ALF,REPS) = 0.
        RHTSTR(ALF,REPS) = 0.
    173 CONTINUE
172 CONTINUE

```

```

                RSHTBR(ALF,REPS) = 0.
173      CONTINUE
172 CONTINUE

***// SET FLAG TO 1 IF ALL COMPONENTS HAVE SAME NO. OF MISSION TESTS****
      FLAG=1
      DO 50 I=1,K -1
        IF((N(I) - N(I+1)).NE.0) THEN
          FLAG=0
        ELSE
          END IF
50 CONTINUE
      PRINT *, 'FLAG IS: ', FLAG

***// MAIN PROGRAM OUTER LOOP START(EVERY LOOP IS ONE REPLICATION)//***
      ZFPREP = 0.
      FAILS = 0
      ZFAILS = 0
      COUNT1 = 0
      TOTREP = 0
      LOOP = 0
10 IF(LOOP.LT.MAXREP) THEN
      IF(TOTREP.LT.MAXRUN) THEN
        SELCTA = 1
        SELCTB = 2

***// FILL ARRAY KEY(REPS) WITH INTEGERS 1 TO K TO BE USED AS OUTPUT
***// OF THE SUBROUTINE SHSORT

      DO 95 REPS=1, MAXREP
        KEY1(REPS) = REPS
        KEY2(REPS) = REPS
        KEY3(REPS) = REPS
        KEY4(REPS) = REPS
95 CONTINUE

***// CALCULATE NMAX NOT TO PRINT LONGER THAN THE MAX SAMPLE SIZE //***
***// CALCULATE THE MAXIMUM NO. OF TRIALS AND ITS INDEX NO. //***

      CALL IMAX(N,K,NMAX,NINDX)

***// CALCULATE THE QI'S FROM THE GIVEN MASTER Q AND THE AI'S

      DO 115 I=1, K
        QI(I) = MSTRQ * AI(I)
115 CONTINUE

      DO 120 I=1,15
        DO 125 J=1,500
          UNIRV(I,J) = 999.
          TRIALS(I,J) = 99999
125 CONTINUE

```

```

120 CONTINUE

***// CALCULATE THE SCALING FACTOR 'SCALEN'
CALL USMNMX(QI,K,INC,MINQI,MAXQI)
SCALEN = MAXQI / MINQI

***// DRAW UNIFORM (0,1) RV'S AND CONVERT TO BERNOULLI TRIALS
DO 130 I=1, K
  CALL SRND(SEED, TEMP, N(I), MULT, SORT)
  DO 135 J=1, N(I)
    UNIRV(I,J) = TEMP(J)
    IF (UNIRV(I,J).LE. 1 - QI(I)) THEN
      TRIALS(I,J) = 0
    ELSE
      TRIALS(I,J) = 1
    END IF
  135 CONTINUE
130 CONTINUE

***// CALCULATE THE NO. OF FAILURES FOR EACH COMPONENT
DO 150 I=1, K
  FI(I) = 0
150 CONTINUE

***// CALCULATE THE F SUB I'S AND THE GRAND TOTAL NO. OF FAILURES
BIGF = 0
DO 155 I=1, K
  DO 160 J=1, N(I)
    FI(I) = FI(I) + TRIALS(I,J)
  160 CONTINUE
155 CONTINUE

***// CALCULATE THE QHAT SUB I'S: F SUB I'S DIVIDED BY N SUB I'S
IF(FI(I).EQ.0) THEN
  QHATI(I) = 1. / (SCALEN * N(I))
  ZFPREP = ZFPREP + 1
ELSE
  QHATI(I) = REAL(FI(I)) / N(I)
END IF
BIGF = BIGF + FI(I)
155 CONTINUE

***// FIND THE MAX OF THE INDIVIDUAL COMPONENT UNRELIABILITIES
CALL RMAX(QHATI, K, QHTMAX, QINDX)

IF(PRNT.EQ.1) THEN
  WRITE(1,0007)
  WRITE(1,C1C15)
  WRITE(1,3334) QI
  WRITE(1,0001)

```

```

        WRITE(1,C1C15)
        DO 140 J=1,NMAX
            WRITE(1,1111) (UNIRV(I,J), I=1, K)
140    CONTINUE
        WRITE(1,0002)
        WRITE(1,C1C15)
        DO 145 J=1,NMAX
            WRITE(1,2222) (TRIALS(I,J), I=1, K)
145    CONTINUE
        WRITE(1,0003)
        WRITE(1,C1C15)
        WRITE(1,3333) FI
        WRITE(1,0005)
        WRITE(1,C1C15)
        WRITE(1,3335) N
        WRITE(1,0004)
        WRITE(1,C1C15)
        WRITE(1,3334) QHATI
        WRITE(1,'(/' THE MAXIMUM Q HAT SUB I IS: ', T40, F8.5)') QHTMAX
        WRITE(1,'(/' THE MAXI Q HAT SUB I IS ELMNT NO.: ', T40, I5)') QINDX
        WRITE(1,'(/' THE GRAND TOTAL NO. OF FAILURES IS: ', T40, I5)') BIGF
        ELSE
        ENDIF

```

***// TEST FOR A REP WITH AT LST TWO COMP WITH AT LST ONE FAILURE EACH

```

        DO 162 J=1, K
            NN(J) = 0
            IF(FI(J).GE.1) THEN
                COUNT1 = COUNT1 + 1
                NN(J)= N(J)
            ELSE
                NN(J) = N(J) * SCALEN
            END IF
162    CONTINUE
        IF(COUNT1.EQ.0) THEN
            ZFAILS = ZFAILS + 1
        ELSE
            FAILS = FAILS + 1
        END IF
        IF(COUNT1.GE.2) THEN
            LOOP = LOOP + 1
            TOTREP = TOTREP + 1
        ELSE
            TOTREP = TOTREP + 1
            GO TO 10
        END IF

```

***// CALCULATE THE AHAT SUB I'S (WEIGHT ESTIMATES)

***//

```

        SUMNAI = 0.
        DO 165 I=1, K
            AHATI(I) = QHATI(I) / QHTMAX
        *   +(FI(L),L=1,K)
        *   +(NN(L),L=1,K)
        SUMNAI = SUMNAI + NN(I) * AHATI(I)

```

```

165  CONTINUE
      IF(PRNT.EQ.1) THEN
          WRITE(1,0006)
          WRITE(1,C1C15)
          WRITE(1,3334) AHATI
      ELSE
      END IF

***// CALCULATE 1 REPLICATION OF UPPR ALFA C.L. ON SYSTEM RELIABILITY

      DEGFR(LOOP) = 2 * (1 + BIGF)

      DO 170 ALF=1, MAXALF
          CALL MDCHI(1 - ALFA(ALF),DEGFR(LOOP),CHISQ(ALF,LOOP), ERROR)
          QHTUPR(ALF,LOOP) = CHISQ(ALF,LOOP) / (2 * SUMNAI)
          IF(FLAG.EQ.1) THEN
              RHTSTR(ALF,LOOP) = 1 -(CHISQ(ALF,LOOP) / REAL(2*N(1)))
          ELSE
              END IF
          *      +      (ALF,LOOP), ALFA(ALF)

***// CALCULATE VALUE OF THE SYSTEM RELIABILITY FOR COMPNTS. IN SERIES

          CALL RHTSRS(QHTUPR(ALF,LOOP), AHATI,K, RSHAT(ALF,LOOP))
          *      +T40,F8.5') RSHAT(ALF,LOOP)

***// CALCULATE VALUE OF THE SYSTEM RELIABILITY FOR BRIDGE STRUCTURE ***
          CALL RHTBRG(QHTUPR(ALF,LOOP),AHATI,K,RSHTBR(ALF,LOOP))

170  CONTINUE

***// THIS ELSE AND ENDIF ARE FOR THE TEST AGAINST MAXRUN          //***
      ELSE
          WRITE(1,(' ' ' '),'PROGRAM EXCEEDED THE MAX NO. OF RUNS',
          + ' ALLOWED OF: ',I6)') TOTREP
          GOTO 9999

      END IF
      GOTO 10
      END IF

***// SORT THE ARRAYS OF SYSTEM UNRELIABILITIES(1 FOR EACH CONF. LEVEL)

      DO 700 ALF=1, MAXALF
          DO 800 REPS=1, MAXREP
              TRANSQ(REPS) = QHTUPR(ALF,REPS)
              TRANSP(REPS) = RSHAT(ALF,REPS)
              TRNSTR(REPS) = RHTSTR(ALF,REPS)
              TRANBR(REPS) = RSHTBR(ALF,REPS)
          800  CONTINUE
              CALL SHSORT(TRANSQ,KEY1,MAXREP)
              CALL SHSORT(TRANSP,KEY2,MAXREP)
              CALL SHSORT(TRNSTR,KEY3,MAXREP)
              CALL SHSORT(TRANBR,KEY4,MAXREP)
          DO 900 REPS=1, MAXREP

```



```

OHTUPR(ALF,REPS) = TRANSQ(REPS)
RSHAT(ALF,REPS) = TRANSR(REPS)
RHTSTR(ALF,REPS) = TRNSTR(REPS)
RSHTBR(ALF,REPS) = TRANBR(REPS)
900 CONTINUE
700 CONTINUE

```

***// PRINT OUTPUT REPORT HEADINGS

//***

```

WRITE(1,6666)
WRITE(1,6667) MAXREP
WRITE(1,6668) K
WRITE(1,6770) SCALEN
WRITE(1,6669)
IF(K.EQ.5) THEN
  WRITE(1,6699)
ELSE
  END IF
WRITE(1,6670) MSTRQ
WRITE(1,6671)
WRITE(1,C1C15)
WRITE(1,3334) AI
WRITE(1,0007)
WRITE(1,C1C15)
WRITE(1,3334) QI
WRITE(1,0005)
WRITE(1,C1C15)
WRITE(1,3335) N
WRITE(1,6674)
WRITE(2,6666)
WRITE(2,6667) MAXREP
WRITE(2,6668) K
WRITE(2,6770) SCALEN
WRITE(2,6669)
IF(K.EQ.5) THEN
  WRITE(1,6699)
ELSE
  END IF
WRITE(2,6670) MSTRQ
WRITE(2,6671)
WRITE(2,C1C15)
WRITE(2,3334) AI
WRITE(2,0007)
WRITE(2,C1C15)
WRITE(2,3334) QI
WRITE(2,0005)
WRITE(2,C1C15)
WRITE(2,3335) N
WRITE(2,6674)
WRITE(2,'(''SORTED RSHAT 1 IS: '',/15(F8.5))')
+(RSHAT(1,REPS), REPS=1, MAXREP)
WRITE(2,'(''SORTED RSHAT 2 IS: '',/15(F8.5))')
+(RSHAT(2,REPS), REPS=1, MAXREP)
IF(FLAG.EQ.1) THEN
  WRITE(2,'(''SORTED RHTSTR 1 IS: '',/10(F8.5))')

```

```

***// COMPUTE THE VALUE RS OF THE TRUE SYSTEM REL. FNCTN. (SERIES SYSTEM)
***// AND FOR THE 5-COMPONENT BRIDGE STRUCTURE

```

```

***// COMPUTE THE DIFFERENCE 'DELTAR' BTWN. RS AND RSHAT OF THE THEO
***// RETICAL QUANTILE GIVEN BY ALFA(MUST USE SORTED RSHAT ARRAY)

```

49

```

PRINT *, 'QUANTL(1) IS:', QUANTL(1)
PRINT *, 'QUANTL(2) IS:', QUANTL(2)

***// FIND THE TRUE CONFIDENCE LEVEL OF THE SYSTEM REL. ESTIMATE //***
***// ***** RSHAT ***** //***

WRITE(1,6676)
DO 400 ALF=1,MAXALF
  TRUQNT(ALF) = 0
  DO 500 REPS=1, MAXREP
    DIFF(REPS) = RS - RSHAT(ALF,REPS)
    CONTINUE
  DO 600 REPS=1, MAXREP
    IF(ABS(DIFF(REPS)).LE.EPS) THEN
      TRUQNT(ALF) = REPS
      WRITE(1,(' ',/, 'TRUE CONFIDENCE LIMIT IS:',
+      F8.4)')
+      (TRUQNT(ALF) / REAL(MAXREP)) * 100.
      GO TO 620
    ELSEIF(DIFF(REPS).LT.0.) THEN
      TRUQNT(ALF) = REPS
      GO TO 610
    ELSE
      END IF
  CONTINUE
600 CONTINUE
610 IF(TRUQNT(ALF).EQ.0.) THEN
  WRITE(1,4443) ALFA(ALF)
  WRITE(1,(' ',/, 'THE SMALLEST',
+  ' DIFFERENCE BETWEEN RS AND RSHAT IS:',F10.5)') DIFF(
+  MAXREP)
  ELSEIF(TRUQNT(ALF).EQ.1.) THEN
  WRITE(1,4442) ALFA(ALF)
  WRITE(1,(' ',/, 'ALL RSHAT',
+  ' ARE GREATER THAN RS'))
  ELSEIF(ABS(DIFF(TRUQNT(ALF))).LE.ABS(DIFF(TRUQNT(ALF) - 1)))
  THEN
  WRITE(1,4444) ALFA(ALF),
+  (TRUQNT(ALF) / REAL(MAXREP)) * 100.
  WRITE(1,4445) RSHAT(ALF,TRUQNT(ALF))
  WRITE(1,4446)
  ELSE
  WRITE(1,4444) ALFA(ALF),
+  ((TRUQNT(ALF)-1) / REAL(MAXREP)) * 100.
  WRITE(1,4445) RSHAT(ALF,TRUQNT(ALF)-1)
  WRITE(1,4447)
620 END IF
400 CONTINUE

***// FIND THE TRUE CONFIDENCE LEVEL OF THE SYSTEM REL. ESTIMATE //***
***// ***** RSHTBR (BRIDGE) ***** //***

IF(K.EQ.5) THEN
DO 401 ALF=1,MAXALF
  TRUQNT(ALF) = 0
  DO 501 REPS=1, MAXREP

```

```

501      DIFF(REPS) = RSBRDG - RSHTBR(ALF,REPS)
      CONTINUE
      DO 601 REPS=1, MAXREP
        IF(ABS(DIFF(REPS)).LE.EPS) THEN
          TRUQNT(ALF) = REPS
          WRITE(1,(' ','',/'TRUE CONFIDENCE LIMIT IS:',
+           F8.4)')
+           (TRUQNT(ALF) / REAL(MAXREP)) * 100.
          GO TO 621
        ELSEIF(DIFF(REPS).LT.0.) THEN
          TRUQNT(ALF) = REPS
          GO TO 611
        ELSE
          END IF
601      CONTINUE
611      IF(TRUQNT(ALF).EQ.0.) THEN
        WRITE(1,4443) ALFA(ALF)
        WRITE(1,(' ','',/'THE SMALLEST',
+         'DIFFERENCE BETWEEN RSBRDG AND RSHTBR IS:',
+         F10.5)') DIFF(MAXREP)
        ELSEIF(TRUQNT(ALF).EQ.1.) THEN
        WRITE(1,4442) ALFA(ALF)
        WRITE(1,(' ','',/'ALL RSHTBR',
+         'ARE GREATER THAN RSBRDG'))
        ELSEIF(ABS(DIFF(TRUQNT(ALF))).LE.ABS(DIFF(TRUQNT(ALF) - 1)))
+         THEN
        WRITE(1,4444) ALFA(ALF),
+         (TRUQNT(ALF) / REAL(MAXREP)) * 100.
        WRITE(1,4449) RSHTBR(ALF,TRUQNT(ALF))
        WRITE(1,4446)
        ELSE
        WRITE(1,4444) ALFA(ALF),
+         ((TRUQNT(ALF)-1) / REAL(MAXREP)) * 100.
        WRITE(1,4449) RSHTBR(ALF,TRUQNT(ALF)-1)
        WRITE(1,4447)
621      END IF
401      CONTINUE
      ELSE
      END IF

```

```

****// FIND THE TRUE CONFIDENCE LEVEL OF THE SYSTEM REL. ESTIMATE //****
****// ***** RHTSTR ***** //****

```

```

      IF(FLAG.EQ.1) THEN
      DO 4400 ALF=1,MAXALF
      TRUQNT(ALF) = 0
      DO 5500 REPS=1, MAXREP
        DIFF(REPS) = RS - RHTSTR(ALF,REPS)
5500      CONTINUE
      DO 6600 REPS=1, MAXREP
        IF(ABS(DIFF(REPS)).LE.EPS) THEN
          TRUQNT(ALF) = REPS
          WRITE(1,(' ','',/'TRUE CONFIDENCE LIMIT IS:',
+           F8.4)')
+           (TRUQNT(ALF) / REAL(MAXREP)) * 100.

```

```

        GO TO 6620
    ELSEIF(DIFF(REPS).LT.0.) THEN
        TRUQNT(ALF) = REPS
        GO TO 6610
    ELSE
        END IF
6600 CONTINUE
6610 IF(TRUQNT(ALF).EQ.0.) THEN
        WRITE(1,4443) ALFA(ALF)
        WRITE(1,(' ','',/'THE SMALLEST',
+         '' DIFFERENCE BETWEEN RS AND RHTSTR IS: ',
+         F9.5)') DIFF(MAXREP)
    ELSEIF(TRUQNT(ALF).EQ.1.) THEN
        WRITE(1,4442) ALFA(ALF)
        WRITE(1,(' ','',/'ALL RHTSTR',
+         '' ARE GREATER THAN RS''))
    ELSEIF(ABS(DIFF(TRUQNT(ALF))).LE.ABS(DIFF(TRUQNT(ALF) - 1)))
+ THEN
        WRITE(1,4444) ALFA(ALF),
+         (TRUQNT(ALF) / REAL(MAXREP)) * 100.
        WRITE(1,4448) RHTSTR(ALF,TRUQNT(ALF))
        WRITE(1,4446)
    ELSE
+         WRITE(1,4444) ALFA(ALF),
+         ((TRUQNT(ALF)-1) / REAL(MAXREP)) * 100.
        WRITE(1,4448) RHTSTR(ALF,TRUQNT(ALF)-1)
        WRITE(1,4447)
6620 END IF
4400 CONTINUE
    ELSE
    END IF

```

***// PRINT THE ARRAYS PERTINENT TO THE OUPUT OF EACH REPLICATION ***

```

    IF(PRNT.EQ.1) THEN
        I = 1
185 WRITE(1,REPSHD) ALFA(SELCTA), ALFA(SELCTA),
+ALFA(SELCTB),ALFA(SELCTB),ALFA(SELCTA),ALFA(SELCTA),ALFA(SELCTB),
+ALFA(SELCTB)
175 IF(I.GE.(MAXREP + 1)) THEN
        GOTO 180
    ELSE
        IF( (I.EQ.71).OR.(I.EQ.211).OR.(I.EQ.351).OR.(I.EQ.491).OR.
+         (I.EQ.631).OR.(I.EQ.771).OR.(I.EQ.911).OR.(I.EQ.1051) ) THEN
            I = I + 70
            WRITE(1,(' '+''))
            GOTO 185
        ELSE
            WRITE(1,3336) I, INT(DEGFR(I)), CHISQ(1,I), QHTUPR(1,I),
+             CHISQ(2,I), QHTUPR(2,I)
            END IF
            IF(I + 70.LE.MAXREP) THEN
                WRITE(1,3337) I+70,INT(DEGFR(I+70)),CHISQ(1,I+70),
+                 QHTUPR(1,I+70),CHISQ(2,I+70),QHTUPR(2,I+70)
            ELSE

```

```

        END IF
        I = I + 1
        GOTO 175
180  END IF
    ELSE
    ENDIF
9999 WRITE(1,('THE TOTAL NO OF REPS WAS:',I8)) TOTREP
    WRITE(1,('THE TOTAL NO OF EFFECTIVE REPS WAS:',I8)) LOOP
    WRITE(1,('THE TOTAL NO OF NO FAILURE RUNS WAS:',I8)) ZFAILS
    WRITE(1,('THE TOTAL NO OF RUNS WITH FAILURES WAS:',I8)) FAILS
    WRITE(1,('AVG NO OF COMPONENTS WITH NO FAILURES PER REP WAS:',
+ F5.2)) ZFPREP / MAXREP
0008 FORMAT (/ 3X,'C 1',5X,'C 2',
+ 5X,'C 3',5X,'C 4',5X,'C 5',5X,'C 6',5X,'C 7',5X,
+ 'C 8',5X,'C 9',5X,'C 10',4X,'C 11',4X,
+ 'C 12',4X,'C 13',4X,'C 14',4X,'C 15')
0009 FORMAT(/1X,'REP NO',2X,'DF',1X,'CHISQR(',F4.3,')',1X,
+ 'QHTUPR(',F4.3,')',1X,'CHISQR(',F4.3,')',1X,'QHTUPR(',F4.3,')',
+ 2X,'REP NO',2X,'DF',1X,'CHISQR(',F4.3,')',1X,
+ 'QHTUPR(',F4.3,')',1X,'CHISQR(',F4.3,')',1X,'QHTUPR(',F4.3,')')/
0001 FORMAT (///'UNIFORM RANDOM DEVIATES ARE:')
0002 FORMAT (///'BERNOULLI TRIALS ARE:')
0003 FORMAT (///'TOTAL NO. OF FAILURES FOR EACH COMPONENT:')
0004 FORMAT (///'ESTIMATED UNRELIABILITY FOR EACH COMPONENT:')
0005 FORMAT (///'TOTAL NUMBER OF MISSION TESTS:')
0006 FORMAT (///'ESTIMATED WEIGHTS FOR EACH COMPONENT:')
0007 FORMAT (///'Q I FOR EACH COMPONENT:')
1111 FORMAT (15F8.5)

2222 FORMAT (/1X,15(I4,4X))
3333 FORMAT (/1X,15(I4,4X))
3334 FORMAT (/15F8.5)
3335 FORMAT (/1X,15(I4,4X))
3336 FORMAT (T3,I4,T9,I3,T13,F11.5,T27,F8.5,T39,F11.5,T53,F8.5)
3337 FORMAT ('+',T67,I4,T73,I3,T77,F11.5,T91,F8.5,T103,F11.5,T117,F8.5)
4442 FORMAT (' ',///'THE RESULTING (1 - ',F4.3,') CONFIDENCE ',
+ 'LIMIT IS:',T50,' 00.000 ')
4443 FORMAT (' ',///'THE RESULTING (1 - ',F4.3,') CONFIDENCE ',
+ 'LIMIT IS:',T50,' 100.0000 ')
4444 FORMAT (' ',///'THE RESULTING (1 - ',F4.3,') CONFIDENCE ',
+ 'LIMIT IS:',T50,F8.4)
4445 FORMAT (' ',/'THE RSHAT VALUE CLOSEST TO RS IS: ',T51,F8.5)
4446 FORMAT (' ',/'(FIRST NEGATIVE DIFFERENCE)')
4447 FORMAT (' ',/'(ELEMENT PRECEEDING FIRST NEGATIVE DIFFERENCE)')
4448 FORMAT (' ',/'THE RHTSTR VALUE CLOSEST TO RS IS: ',T51,F8.5)
4449 FORMAT (' ',/'THE RSHTBR VALUE CLOSEST TO RSBRDG IS: ',T51,F8.5)
5555 FORMAT (' ',///'THE ',I4,'(1-',F4.3,') QUANTILE IS:',T49,F8.3)
5556 FORMAT (' ',/'THE VALUE OF RSHAT FOR THAT QUANTILE IS:',T51,F8.5)
5557 FORMAT (' ',/'THE DIFFERENCE(RS - RSHAT) IS:',T51,F8.5)
5656 FORMAT (' ',/'THE VALUE OF RHTSTR FOR THAT QUANTILE IS:',T51,F8.5)
5666 FORMAT (' ',/'THE VALUE OF RSHTBR FOR THAT QUANTILE IS:',T51,F8.5)
5657 FORMAT (' ',/'THE DIFFERENCE(RS - RHTSTR) IS:',T51,F8.5)
5667 FORMAT (' ',/'THE DIFFERENCE(RS - RSHTBR) IS:',T51,F8.5)
5755 FORMAT (' ',///'SINCE THE NO. OF MISSION TESTS IS THE SAME FOR',
+ ' ALL COMPONENTS THE CLOSED FORM SERIES SYSTEM RELIABILITY ',
+ "'RHTSTR' IS COMPUTED'")

```

```

6666 FORMAT ('+', '*****',
+ '* RUN INPUT SETTINGS FOR ADJUSTED SUM OF THE NI AI *****',
+ '*****')
6667 FORMAT (' ', '//', 'NUMBER OF REPLICATIONS:', T50, I4)
6668 FORMAT (' ', '//', 'NUMBER OF COMPONENTS:', T50, I4)
6669 FORMAT (' ', '//', 'SYSTEM RELIABILITY FUNCTION:', T50, 'SERIES')
6699 FORMAT (' ', '//', 'SYSTEM RELIABILITY FUNCTION:', T50, 'BRIDGE')
6670 FORMAT (' ', '//', 'MASTER UNRELIABILITY USED:', T50, F8.5)
6770 FORMAT (' ', '//', 'ZERO FAILURE SCALING FACTOR:', T50, F5.2)
6671 FORMAT (' ', '//', 'INPUT WEIGHTS(A SUB I'S):')
6674 FORMAT ('+', '///', '*****',
+ '*R U N R E S U L T S*****',
+ '*****')
6675 FORMAT ('+', '///', '*****',
+ ' ESTIMATE ERRORS *****',
+ '*****')
6676 FORMAT ('+', '///', '*****',
+ ' TRUE CONFIDENCE LIMITS *****',
+ '*****')
END

```

APPENDIX C. INTERVAL ESTIMATING PROCEDURE 3

PROGRAM ZFYSCY

```

*****
*
*   TITLE:  BINOMIAL INTERVAL ESTIMATION PROCEDURE
*           ZERO FAILURES DISALLOWED; WITH SCALING
*   AUTHOR:  E. F. BELLINI, LT, USN
*   DATE:   NOV 89
*
*   THIS PROGRAM COMPUTES THE TRUE CONFIDENCE LEVEL FOR THE ESTIMATE
*   RELIABILITY OF A SERIES AND BRIDGE SYSTEM GIVEN THE RELIABILITY
*   OF THEIR COMPONENTS
*
*   IN ITS PRESENT CONFIGURATION THIS PROGRAM IS SET UP TO RUN 12
*   TIMES EACH TIME PRODUCING 1000 REPLICATIONS USING A DIFFERENT
*   SET OF INPUT DATA.  RUN THE PROGRAM FROM CMS BY TYPING 'B1 EXEC'.
*   THE REXX EXEC PROGRAM
*   'B1' CALLS THE INPUT FILES TO BE READ AND NAMES THE 12 OUTPUT
*   FILES RESULTING FROM THE 12 CONSECUTIVE RUNS.  BY EDITING THE
*   INDEX COUNTERS I, J, K OF THE 'B1' EXEC ONE CAN RUN ANY USER-
*   SPECIFIC RUN FROM JUST ONE RUN TO ALL 12.
*
*   VARIABLES USED
*
*   AHATI  :  WEIGHT ESTIMATES FOR EACH COMPONENT
*   AI      :  INPUT WEIGHTS FOR EACH COMPONENT
*   ALFA    :  LEVELS OF SIGNIFICANCE
*   BIGF    :  TOTAL NO. OF FAILURES FOR EACH REPLICATION
*   CHISQ   :  CHI-SQUARE RANDOM VARIABLE VALUE
*   COUNT1  :  COUNTS THE NO. OF COMPONENTS WITH FAILURES
*   C1C15   :  FORMAT LABEL
*   DEGFR   :  DEGREES OF FREEDOM
*   DELBRG  :  DIFFERENCE FOR BRIDGE SYSTEM
*   DELSTR  :  DIFFERENCE FOR SERIES SYSTEM- CLOSED FORM
*   DELTAR  :  DIFFERENCE FOR SERIES SYSTEM
*   DIFF    :  DIFFERENCE (TRUE REL. - ESTIMATED REL.)
*   EPS     :  SMALL QUANTITY(CONSTANT)
*   ERROR   :  PARAMETER FOR IMSL ROUTINE
*   FAILS   :  COUNTS NO. OF REPLICATIONS WITH AT LST. 1 FAILURE
*   FI      :  NO. OF FAILURES FOR EACH COMPONENT(ALL MISSION TST)
*   FLAG    :  1 IF ALL COMP. HAVE SAME NO. OF MISSION TESTS
*   INC     :  INCREMENT STEP SIZE FOR ROUTINE USMNMX
*   KEY1    :  ARRAY OF INDECS FOR ROUTINE SHSORT
*   KEY2    :  ARRAY OF INDECS FOR ROUTINE SHSORT
*   KEY3    :  ARRAY OF INDECS FOR ROUTINE SHSORT
*   KEY4    :  ARRAY OF INDECS FOR ROUTINE SHSORT
*   KK      :  ARRAY SIZING PARAMETER FOR THE MAX NO OF COMPONENTS
*   LOOP    :  COUNTS NO. OF REPLICATION PERFORMED
*   MAXALF  :  MAX NO. OF SIGNIFICANT LEVELS DESIRED(ARRAY SIZING)
*   MAXREP  :  MAX NO. OF REPLICATIONS
*   MAXRUN  :  MAX NO. OF PROGRAM ITERATIONS ALLOWED
*   MSTRQ   :  MASTER UNRELIABILITY(USED WITH AI'S TO CALC. QI'S)

```



```

*      MULT   : MULTIPLIER FOR RANDOM NO. GENERATOR SRND      *
*      N       : NO. OF MISSION TEST FOR EACH COMPONENT        *
*      NIMAX   : MAX NO. OF MISSION TESTS                      *
*      NIMIM   : MIN NO. OF MISSION TESTS                      *
*      NINDX   : INDEX NO. OF MAX NO. OF MISSION TESTS        *
*      NIREAL  : NO. OF MISSION TESTS TRANSFORMED TO REAL      *
*      NMAX    : MAX NO. OF MISSION TESTS FOR OUTPUT CONTROL   *
*      NPRNT   : FLAG FOR DETAILED REPORT OUTPUT               *
*      PRNT    : SAME AS ABOVE(PARAMETER)                      *
*      QHATI   : UNRELIABILITY ESTIMATES FOR EACH COMPONENT    *
*      QHTMAX  : LARGEST QHATI                                  *
*      QHTUPR  : UPPER LIMIT ON SYSTEM UNRELIABILITY          *
*      QI      : INPUT UNRELIABILITY FOR EACH COMPONENT        *
*      QINDX   : INDEX                                          *
*      QUANTL  : QUANTILE                                       *
*      REPSHD  : REPLICATIONS HEADING FORMAT NUMBER           *
*      RHTSTR  : SERIES SYSTEM RELIABILITY ESTIMATE(CLOSED FORM)
*      RS      : TRUE SERIES SYSTEM RELIABILITY                *
*      RSBRDG  : TRUE BRIDGE SYSTEM RELIABILITY                *
*      RSHAT   : SERIES SYSTEM RELIABILITY ESTIMATE            *
*      RSHTBR  : BRIDGE SYSTEM RELIABILITY ESTIMATE            *
*      SEED    : PARAMETER                                      *
*      SELCTA  : SIGNIFICANCE LEVEL SELECTION                  *
*      SELCTB  : SIGNIFICANCE LEVEL SELECTION                  *
*      SORT    : PARAMETER FOR ROUTINE SRND                    *
*      SUMNAI  : SUM OF THE PRODUCT OF NI'S AND AI'S           *
*      TEMP    : TEMPORARY ARRAY                                *
*      TOTREP  : TOTAL NUMBER OF PROGRAM ITERATIONS            *
*      TRANBR  : TEMPORARY ARRAY                                *
*      TRANSQ  : TEMPORARY ARRAY                                *
*      TRANSR  : TEMPORARY ARRAY                                *
*      TRIALS  : BERNOULLI TRIALS ARRAY (2-DIM)                *
*      TRNSTR  : TEMPORARY ARRAY                                *
*      TRUQNT  : TRUE QUANTILE                                   *
*      UNIRV   : UNIFORM RANDOM DEVIATES (2-DIM)              *
*      ZFAILS  : TOTAL NUMBER OF REPLICATIONS WITH ZERO FAILURES
*      ZFPREP  : NO. OF COMPTS. WITH ZERO FAILURES PER REPLICATION
*
*****

```

```

PARAMETER (KK=10,MAXALF=2,NPRNT=0)
PARAMETER (MAXREP=1000, MAXRUN=10000, EPS=.000001)

```

```

REAL*4 UNIRV(15,1000),TEMP(1000),QI(KK), AI(KK), AHATI(KK)
REAL*4 QHATI(KK), NMAX, NNMAX, QHTMAX, ALFA(MAXALF)
REAL*4 DF(5),AALFA(5),SUMNAI,RSHAT(MAXALF,MAXREP),RS
REAL*4 KEY1(MAXREP),KEY2(MAXREP),KEY3(MAXREP),TRNSTR(MAXREP)
REAL*4 DEGFR(MAXREP), QHTUPR(MAXALF,MAXREP),CHISQ(MAXALF,MAXREP)
REAL*4 RHTSTR(MAXALF,MAXREP)
REAL*4 DELTAR(MAXALF), TRANSQ(MAXREP),TRANSR(MAXREP),DIFF(MAXREP)
REAL*4 DELSTR(MAXALF), NN(KK)
REAL*4 RSHTBR(MAXALF,MAXREP),DELBGR(MAXALF),KEY4(MAXREP)
REAL*4 TRANBR(MAXREP), RSBRDG
REAL*4 SCALEN, MINQI, MAXQI, ZFPREP,MSTRQ

```

```

INTEGER SEED, MULT, SORT, TRIALS(15,1000), BIGF, FI(KK), N(KK)

```

```

INTEGER NINDX, QINDX, ERROR, REPS, SELCTA, SELCTQ, TOTREP
INTEGER COUNT1, C1C15, REPSHD, SELCTB, ALF, FLAG, LOOP, PRNT
INTEGER QUANTL(MAXALF), TRUQNT(MAXALF), ZFAILS, FAILS
INTEGER INC

```

```

DATA SEED/123457/, MULT/1/, INC/1/
DATA AALFA/.01,.05,.9,.95,.99/, DF/1,5,10,30,40/
DATA ALFA/.20,.050/
* DATA MSTRQ/0.1, .05/
* DATA AI/.20,.10,.05,.05,.05/
* DATA AI/.20,.10,.05,.05,.05,.05,.05,.05,.05/
* DATA AI/.05,.05,.05,.05,.05,.05,.05,.05,.05/
* DATA AI/.05,.05,.05,.05,.05,.05,.05,.05,.05,.05,.05,.05,
* +.05,.05/
* DATA AI/.1,.1,.1,.1,.1,.05,.05,.2,.25,.5/
* DATA AI/.1,.1,.1,.05,.2/
* DATA N/100,100,100,100,100/
* DATA N/10,6,5,2,10,4,5,6,7,2/
* DATA N/50,50,50,50,50,50,50,50,50,50/
* DATA N/100,100,100,100,100,100,100,100,100,100/
* DATA N/300,300,300,300,300,300,300,300,300,300/
* DATA N/20,20,20,20,20,20,20,20,20,20/
* DATA N/1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,
* +1000,1000,1000,1000/
DATA SORT/0/

```

```

ASSIGN 8 TO C1C15
ASSIGN 9 TO REPSHD

```

```

* CALL EXCMS('FILEDEF 01 DISK B OUTPUT A1 (LRECL 132 ')
* CALL EXCMS('FILEDEF 02 DISK JNK OUTPUT A1 (LRECL 132 ')

```

```

SELCTQ = 1
PRNT = NPRNT

```

```

DO 12 I=1,KK
    AI(I) = 9999.
    N(I) = 999999999
12 CONTINUE
    READ(03,*)K,MSTRQ

```

```

    DO 11 I=1,K
        READ(03,*) AI(I),N(I)
11 CONTINUE

```

```

***// INITIALIZE THE QHTUPR ARRAY OF UNRELIABILITY REPLICATIONS, //***
* RSHAT ARRAY OF ESTIMATE SYSTEM RELIABILITY REPLICATIONS *
* AND RHTSTR ARRAY OF EST. SYST. REL. FOR A SERIES SYST WHEN *
***// ALL THE COMPONENT MISSION TESTS ARE EQUAL IN NUMBER //***

```

```

DO 172 ALF=1,MAXALF
    DO 173 REPS=1,MAXREP
        QHTUPR(ALF,REPS) = 0.
        RSHAT(ALF,REPS) = 0.
        RHTSTR(ALF,REPS) = 0.
    173 CONTINUE
172 CONTINUE

```

```

                RSHTBR(ALF,REPS) = 0.
173      CONTINUE
172      CONTINUE

***// SET FLAG TO 1 IF ALL COMPONENTS HAVE SAME NO. OF MISSION TESTS****

      FLAG=1
      DO 50 I=1,K -1
        IF((N(I) - N(I+1)).NE.0) THEN
          FLAG=0
        ELSE
          END IF
50      CONTINUE
      PRINT *, 'FLAG IS: ', FLAG
***// MAIN PROGRAM OUTER LOOP START(EVERY LOOP IS ONE REPLICATION)//***

      ZFPREP = 0.
      FAILS = 0
      ZFAILS = 0
      COUNT1 = 0
      TOTREP = 0
      LOOP = 0
10      IF(LOOP.LT.MAXREP) THEN
        IF(TOTREP.LT.MAXRUN) THEN
          SELCTA = 1
          SELCTB = 2

***// FILL ARRAY KEY(REPS) WITH INTEGERS 1 TO K TO BE USED AS OUTPUT
***// OF THE SUBROUTINE SHSORT

          DO 95 REPS=1, MAXREP
            KEY1(REPS) = REPS
            KEY2(REPS) = REPS
            KEY3(REPS) = REPS
            KEY4(REPS) = REPS
95          CONTINUE

***// CALCULATE NMAX NOT TO PRINT LONGER THAN THE MAX SAMPLE SIZE

***// CALCULATE THE MAXIMUM NO. OF TRIALS AND ITS INDEX NO.          //***

          CALL IMAX(N,K,NMAX,NINDX)

***// CALCULATE THE QI'S FROM THE GIVEN MASTER Q AND THE AI'S          //***

          DO 115 I=1, K
            QI(I) = MSTRQ * AI(I)
115          CONTINUE

          DO 120 I=1,15
            DO 125 J=1,500
              UNIRV(I,J) = 999.
              TRIALS(I,J) = 99999
125            CONTINUE
120          CONTINUE

```

***// CALCULATE THE SCALING FACTOR 'SCALEN'

//***

CALL USNMNMX(QI,K,INC,MINQI,MAXQI)

SCALEN = MAXQI / MINQI

// DRAW UNIFORM (0,1) RV'S AND CONVERT TO BERNOULLI TRIALS //

DO 130 I=1, K

CALL SRND(SEED, TEMP, N(I), MULT, SORT)

DO 135 J=1, N(I)

UNIRV(I,J) = TEMP(J)

IF (UNIRV(I,J).LE. 1 - QI(I)) THEN

TRIALS(I,J) = 0

ELSE

TRIALS(I,J) = 1

END IF

135 CONTINUE

130 CONTINUE

***// CALCULATE THE NO. OF FAILURES FOR EACH COMPONENT

//***

DO 150 I=1, K

FI(I) = 0

150 CONTINUE

***// CALCULATE THE F SUB I'S AND THE GRAND TOTAL NO. OF FAILURES

BIGF = 0

DO 155 I=1, K

DO 160 J=1, N(I)

FI(I) = FI(I) + TRIALS(I,J)

160 CONTINUE

***// CALCULATE THE QHAT SUB I'S: F SUB I'S DIVIDED BY N SUB I'S

IF(FI(I).EQ.0) THEN

QHATI(I) = 1. / (SCALEN * N(I))

ZFPREP = ZFPREP + 1

ELSE

QHATI(I) = REAL(FI(I)) / N(I)

END IF

BIGF = BIGF + FI(I)

155 CONTINUE

***// FIND THE MAX OF THE INDIVIDUAL COMPONENT UNRELIABILITIES

CALL RMAX(QHATI, K, QHTMAX, QINDX)

IF(PRNT.EQ.1) THEN

WRITE(1,0007)

WRITE(1,C1C15)

WRITE(1,3334) QI

WRITE(1,0001)

WRITE(1,C1C15)

DO 140 J=1,NMAX

WRITE(1,1111) (UNIRV(I,J), I=1, K)

140 CONTINUE

```

WRITE(1,0002)
WRITE(1,C1C15)
DO 145 J=1,NMAX
    WRITE(1,2222) (TRIALS(I,J), I=1, K)
145 CONTINUE
    WRITE(1,0003)
    WRITE(1,C1C15)
    WRITE(1,3333) FI
    WRITE(1,0005)
    WRITE(1,C1C15)
    WRITE(1,3335) N
    WRITE(1,0004)
    WRITE(1,C1C15)
    WRITE(1,3334) QHATI
    WRITE(1,('THE MAXIMUM Q HAT SUB I IS:', T40, F8.5)) QHTMAX
    WRITE(1,('THE MAXI Q HAT SUB I IS ELMNT NO.:', T40, I5)) QINDX
    WRITE(1,('THE GRAND TOTAL NO. OF FAILURES IS:', T40, I5)) BIGF
ELSE
ENDIF

```

***// TEST FOR A REP WITH AT LST TWO COMP WITH AT LST ONE FAILURE EACH

```

DO 162 J=1, K
    NN(J) = 0
    IF(FI(J).GE.1) THEN
        COUNT1 = COUNT1 + 1
        NN(J)= N(J)
    ELSE
        NN(J) = N(J) * SCALEN
    END IF
162 CONTINUE
    IF(COUNT1.EQ.0) THEN
        ZFAILS = ZFAILS + 1
    ELSE
        FAILS = FAILS + 1
    END IF
    IF(COUNT1.GE.0) THEN
        LOOP = LOOP + 1
        TOTREP = TOTREP + 1
    ELSE
        TOTREP = TOTREP + 1
        GO TO 10
    END IF

```

***// CALCULATE THE AHAT SUB I'S (WEIGHT ESTIMATES)

```

SUMNAI = 0.
DO 165 I=1, K
    AHATI(I) = QHATI(I) / QHTMAX
    SUMNAI = SUMNAI + NN(I) * AHATI(I)
165 CONTINUE
    IF(PRNT.EQ.1) THEN
        WRITE(1,0006)
        WRITE(1,C1C15)
        WRITE(1,3334) AHATI
    ELSE
    END IF

```

```

***// CALCULATE 1 REPLICATION OF UPPR ALFA C.L. ON SYSTEM RELIABILITY

DEGFR(LOOP) = 2 * (1 + BIGF)

DO 170 ALF=1, MAXALF
  CALL MDCHI(1 - ALFA(ALF),DEGFR(LOOP),CHISQ(ALF,LOOP), ERROR)
  QHTUPR(ALF,LOOP) = CHISQ(ALF,LOOP) / (2 * SUMNAI)
  IF(FLAG.EQ.1) THEN
    RHTSTR(ALF,LOOP) = 1 -(CHISQ(ALF,LOOP) / REAL(2*N(1)))
  ELSE
    END IF

***// CALCULATE VALUE OF THE SYSTEM RELIABILITY FOR COMPNTS. IN SERIES

  CALL RHTSRS(QHTUPR(ALF,LOOP), AHATI,K, RSHAT(ALF,LOOP))
*   +T40,F8.5') RSHAT(ALF,LOOP)
***// CALCULATE VALUE OF THE SYSTEM RELIABILITY FOR BRIDGE STRUCTURE ***

  CALL RHTBRG(QHTUPR(ALF,LOOP),AHATI,K,RSHTBR(ALF,LOOP))

170 CONTINUE

***// THIS ELSE AND ENDIF ARE FOR THE TEST AGAINST MAXRUN //***

  ELSE
    WRITE(1,(' ' ' '),'PROGRAM EXCEEDED THE MAX NO. OF RUNS',
+ ' ALLOWED OF: ',I6)' TOTREP
    GOTO 9999

  END IF
  GOTO 10
  END IF

***// SORT THE ARRAYS OF SYSTEM UNRELIABILITIES(1 FOR EACH CONF. LEVEL)

DO 700 ALF=1, MAXALF
  DO 800 REPS=1, MAXREP
    TRANSQ(REPS) = QHTUPR(ALF,REPS)
    TRANSR(REPS) = RSHAT(ALF,REPS)
    TRNSTR(REPS) = RHTSTR(ALF,REPS)
    TRANBR(REPS) = RSHTBR(ALF,REPS)
800  CONTINUE
    CALL SHSORT(TRANSQ,KEY1,MAXREP)
    CALL SHSORT(TRANSR,KEY2,MAXREP)
    CALL SHSORT(TRNSTR,KEY3,MAXREP)
    CALL SHSORT(TRANBR,KEY4,MAXREP)
  DO 900 REPS=1, MAXREP
    QHTUPR(ALF,REPS) = TRANSQ(REPS)
    RSHAT(ALF,REPS) = TRANSR(REPS)
    RHTSTR(ALF,REPS) = TRNSTR(REPS)
    RSHTBR(ALF,REPS) = TRANBR(REPS)
900  CONTINUE
700  CONTINUE

```

***// PRINT OUTPUT REPORT HEADINGS

//***

```
WRITE(1,6666)
WRITE(1,6667) MAXREP
WRITE(1,6668) K
WRITE(1,6770) SCALEN
WRITE(1,6669)
IF(K.EQ.5) THEN
    WRITE(1,6699)
ELSE
END IF
WRITE(1,6670) MSTRQ
WRITE(1,6671)
WRITE(1,C1C15)
WRITE(1,3334) AI
WRITE(1,0007)
WRITE(1,C1C15)
WRITE(1,3334) QI
WRITE(1,0005)
WRITE(1,C1C15)
WRITE(1,3335) N
WRITE(1,6674)
WRITE(2,6666)
WRITE(2,6667) MAXREP
WRITE(2,6668) K
WRITE(2,6770) SCALEN
WRITE(2,6669)
IF(K.EQ.5) THEN
    WRITE(1,6699)
ELSE
END IF
WRITE(2,6670) MSTRQ
WRITE(2,6671)
WRITE(2,C1C15)
WRITE(2,3334) AI
WRITE(2,0007)
WRITE(2,C1C15)
WRITE(2,3334) QI
WRITE(2,0005)
WRITE(2,C1C15)
WRITE(2,3335) N
WRITE(2,6674)
WRITE(2,(''SORTED RSHAT 1 IS: '',/15(F8.5))')
+(RSHAT(1,REPS), REPS=1, MAXREP)
WRITE(2,(''SORTED RSHAT 2 IS: '',/15(F8.5))')
+(RSHAT(2,REPS), REPS=1, MAXREP)
IF(FLAG.EQ.1) THEN
    WRITE(2,(''SORTED RHTSTR 1 IS: '',/10(F8.5))')
+(RHTSTR(1,REPS), REPS=1, MAXREP)
    WRITE(2,(''SORTED RHTSTR 2 IS: '',/10(F8.5))')
+(RHTSTR(2,REPS), REPS=1, MAXREP)
ELSE
END IF
IF(K.EQ.5) THEN
    WRITE(2,(''SORTED RSHTBR 1 IS: '',/10(F8.5))')
+(RSHTBR(1,REPS), REPS=1, MAXREP)
```

1948

9

Figure 1. The effect of the concentration of the *Agaricus bisporus* spores on the growth of *Agaricus bisporus* on the substrate.

•


```

500      CONTINUE
      DO 600 REPS=1, MAXREP
        IF(ABS(DIFF(REPS)).LE.EPS) THEN
          TRUQNT(ALF) = REPS
          WRITE(1,(' ','',/'TRUE CONFIDENCE LIMIT IS:',
+           F8.4)')
+           (TRUQNT(ALF) / REAL(MAXREP)) * 100.
          GO TO 620
        ELSEIF(DIFF(REPS).LT.0.) THEN
          TRUQNT(ALF) = REPS
          GO TO 610
        ELSE
          END IF
600      CONTINUE
610      IF(TRUQNT(ALF).EQ.0.) THEN
          WRITE(1,4443) ALFA(ALF)
          WRITE(1,(' ','',/'THE SMALLEST',
+           '' DIFFERENCE BETWEEN RS AND RSHAT IS:',F10.5)') DIFF(
+           MAXREP)
          ELSEIF(TRUQNT(ALF).EQ.1.) THEN
            WRITE(1,4442) ALFA(ALF)
            WRITE(1,(' ','',/'ALL RSHAT',
+           '' ARE GREATER THAN RS''))
          ELSEIF(ABS(DIFF(TRUQNT(ALF))).LE.ABS(DIFF(TRUQNT(ALF) - 1)))
+           THEN
            WRITE(1,4444) ALFA(ALF),
+           (TRUQNT(ALF) / REAL(MAXREP)) * 100.
            WRITE(1,4445) RSHAT(ALF,TRUQNT(ALF))
            WRITE(1,4446)
          ELSE
+           WRITE(1,4444) ALFA(ALF),
+           ((TRUQNT(ALF)-1) / REAL(MAXREP)) * 100.
            WRITE(1,4445) RSHAT(ALF,TRUQNT(ALF)-1)
            WRITE(1,4447)
620      END IF
400      CONTINUE

```

```

****// FIND THE TRUE CONFIDENCE LEVEL OF THE SYSTEM REL. ESTIMATE //****
****//          ***** RSHTBR (BRIDGE) *****          //****

```

```

      IF(K.EQ.5) THEN
        DO 401 ALF=1,MAXALF
          TRUQNT(ALF) = 0
          DO 501 REPS=1, MAXREP
            DIFF(REPS) = RSBRDG - RSHTBR(ALF,REPS)
501      CONTINUE
          DO 601 REPS=1, MAXREP
            IF(ABS(DIFF(REPS)).LE.EPS) THEN
              TRUQNT(ALF) = REPS
              WRITE(1,(' ','',/'TRUE CONFIDENCE LIMIT IS:',
+               F8.4)')
+               (TRUQNT(ALF) / REAL(MAXREP)) * 100.
              GO TO 621
            ELSEIF(DIFF(REPS).LT.0.) THEN
              TRUQNT(ALF) = REPS

```

```

                GO TO 611
            ELSE
            END IF
601      CONTINUE
611      IF(STRUQNT(ALF).EQ.0.) THEN
                WRITE(1,4443) ALFA(ALF)
                WRITE(1,(' ','',/'THE SMALLEST',
+                ' ' DIFFERENCE BETWEEN RSBRDG AND RSHTBR IS: ',
+                F10.5)') DIFF(MAXREP)
            ELSEIF(STRUQNT(ALF).EQ.1.) THEN
                WRITE(1,4442) ALFA(ALF)
                WRITE(1,(' ','',/'ALL RSHTBR',
+                ' ' ARE GREATER THAN RSBRDG')')
            ELSEIF(ABS(DIFF(STRUQNT(ALF))).LE.ABS(DIFF(STRUQNT(ALF) - 1)))
+            THEN
                WRITE(1,4444) ALFA(ALF),
+                (STRUQNT(ALF) / REAL(MAXREP)) * 100.
                WRITE(1,4449) RSHTBR(ALF,STRUQNT(ALF))
                WRITE(1,4446)
            ELSE
+                WRITE(1,4444) ALFA(ALF),
                ((STRUQNT(ALF)-1) / REAL(MAXREP)) * 100.
                WRITE(1,4449) RSHTBR(ALF,STRUQNT(ALF)-1)
                WRITE(1,4447)
621      END IF
401      CONTINUE
            ELSE
            END IF

```

```

****// FIND THE TRUE CONFIDENCE LEVEL OF THE SYSTEM REL. ESTIMATE ****
****//                ***** RHTSTR *****                ****//

```

```

            IF(FLAG.EQ.1) THEN
                DO 4400 ALF=1,MAXALF
                TRUQNT(ALF) = 0
                DO 5500 REPS=1, MAXREP
                    DIFF(REPS) = RS - RHTSTR(ALF,REPS)
5500      CONTINUE
                DO 6600 REPS=1, MAXREP
                    IF(ABS(DIFF(REPS)).LE.EPS) THEN
                        TRUQNT(ALF) = REPS
                        WRITE(1,(' ','',/'TRUE CONFIDENCE LIMIT IS: ',
+                        F8.4)')
+                        (TRUQNT(ALF) / REAL(MAXREP)) * 100.
                        GO TO 6620
                    ELSEIF(DIFF(REPS).LT.0.) THEN
                        TRUQNT(ALF) = REPS
                        GO TO 6610
                    ELSE
                    END IF
6600      CONTINUE
6610      IF(STRUQNT(ALF).EQ.0.) THEN
                WRITE(1,4443) ALFA(ALF)
                WRITE(1,(' ','',/'THE SMALLEST',
+                ' ' DIFFERENCE BETWEEN RS AND RHTSTR IS: ',

```

```

+      F9.5)' ) DIFF(MAXREP)
      ELSEIF(TRUQNT(ALF).EQ.1.) THEN
        WRITE(1,4442) ALFA(ALF)
        WRITE(1,(' ','',/'ALL RHTSTR'',
+      ' ' ARE GREATER THAN RS'''))
      ELSEIF(ABS(DIFF(TRUQNT(ALF))).LE.ABS(DIFF(TRUQNT(ALF) - 1)))
+      THEN
        WRITE(1,4444) ALFA(ALF),
+      (TRUQNT(ALF) / REAL(MAXREP)) * 100.
        WRITE(1,4448) RHTSTR(ALF,TRUQNT(ALF))
        WRITE(1,4446)
      ELSE
        WRITE(1,4444) ALFA(ALF),
+      ((TRUQNT(ALF)-1) / REAL(MAXREP)) * 100.
        WRITE(1,4448) RHTSTR(ALF,TRUQNT(ALF)-1)
        WRITE(1,4447)
6620      END IF
4400 CONTINUE
      ELSE
      END IF

```

// PRINT THE ARRAYS PERTINENT TO THE OUPUT OF EACH REPLICATION //

```

      IF(PRNT.EQ.1) THEN
        I = 1
185  WRITE(1,REPSHD) ALFA(SELCTA), ALFA(SELCTA),
+ALFA(SELCTB),ALFA(SELCTB),ALFA(SELCTA),ALFA(SELCTA),ALFA(SELCTB),
+ALFA(SELCTB)
175  IF(I.GE.(MAXREP + 1)) THEN
        GOTO 180
      ELSE
        IF( (I.EQ.71).OR.(I.EQ.211).OR.(I.EQ.351).OR.(I.EQ.491).OR.
+      (I.EQ.631).OR.(I.EQ.771).OR.(I.EQ.911).OR.(I.EQ.1051) ) THEN
          I = I + 70
          WRITE(1,(''+'''))
          GOTO 185
        ELSE
          WRITE(1,3336) I, INT(DEGFR(I)), CHISQ(1,I), QHTUPR(1,I),
+      CHISQ(2,I), QHTUPR(2,I)
          END IF
          IF(I + 70.LE.MAXREP) THEN
            WRITE(1,3337) I+70,INT(DEGFR(I+70)),CHISQ(1,I+70),
+      QHTUPR(1,I+70),CHISQ(2,I+70),QHTUPR(2,I+70)
            ELSE
            END IF
          I = I + 1
          GOTO 175
180  END IF
      ELSE
      ENDIF
9999 WRITE(1,(''THE TOTAL NO OF REPS WAS:'' ,I8)') TOTREP
      WRITE(1,(''THE TOTAL NO OF EFFECTIVE REPS WAS:'' ,I8)') LOOP
      WRITE(1,(''THE TOTAL NO OF NO FAILURE RUNS WAS:'' ,I8)') ZFAILS
      WRITE(1,(''THE TOTAL NO OF RUNS WITH FAILURES WAS:'' ,I8)') FAILS
      WRITE(1,(''AVG NO OF COMPONENTS WITH NO FAILURES PER REP WAS:'' ,

```

```

      +F5.2')) ZFPREP / MAXREP
0008 FORMAT (/ 3X,'C 1',5X,'C 2',
      +5X,'C 3',5X,'C 4',5X,'C 5',5X,'C 6',5X,'C 7',5X,
      +'C 8',5X,'C 9',5X,'C 10',4X,'C 11',4X,
      +'C 12',4X,'C 13',4X,'C 14',4X,'C 15')
0009 FORMAT(/1X,'REP NO',2X,'DF',1X,'CHISQR(',F4.3,')',1X,
      +'QHTUPR(',F4.3,')',1X,'CHISQR(',F4.3,')',1X,'QHTUPR(',F4.3,')',
      +2X,'REP NO',2X,'DF',1X,'CHISQR(',F4.3,')',1X,
      +'QHTUPR(',F4.3,')',1X,'CHISQR(',F4.3,')',1X,'QHTUPR(',F4.3,')')/
0001 FORMAT (///'UNIFORM RANDOM DEVIATES ARE:')
0002 FORMAT (///'BERNOULLI TRIALS ARE:')
0003 FORMAT (///'TOTAL NO. OF FAILURES FOR EACH COMPONENT:')
0004 FORMAT (///'ESTIMATED UNRELIABILITY FOR EACH COMPONENT:')
0005 FORMAT (///'TOTAL NUMBER OF MISSION TESTS:')
0006 FORMAT (///'ESTIMATED WEIGHTS FOR EACH COMPONENT:')
0007 FORMAT (///'Q I FOR EACH COMPONENT:')
1111 FORMAT (15F8.5)

2222 FORMAT (/1X,15(I4,4X))
3333 FORMAT (/1X,15(I4,4X))
3334 FORMAT (/15F8.5)
3335 FORMAT (/1X,15(I4,4X))
3336 FORMAT (T3,I4,T9,I3,T13,F11.5,T27,F8.5,T39,F11.5,T53,F8.5)
3337 FORMAT ('+',T67,I4,T73,I3,T77,F11.5,T91,F8.5,T103,F11.5,T117,F8.5)
4442 FORMAT (' ',///'THE RESULTING (1 - ',F4.3,') CONFIDENCE ',
      +'LIMIT IS:',T50,' 00.000 ')
4443 FORMAT (' ',///'THE RESULTING (1 - ',F4.3,') CONFIDENCE ',
      +'LIMIT IS:',T50,'100.0000')
4444 FORMAT (' ',///'THE RESULTING (1 - ',F4.3,') CONFIDENCE ',
      +'LIMIT IS:',T50,F8.4)
4445 FORMAT (' ',/'THE RSHAT VALUE CLOSEST TO RS IS: ',T51,F8.5)
4446 FORMAT (' ',/'(FIRST NEGATIVE DIFFERENCE)')
4447 FORMAT (' ',/'(ELEMENT PRECEDING FIRST NEGATIVE DIFFERENCE)')
4448 FORMAT (' ',/'THE RHTSTR VALUE CLOSEST TO RS IS: ',T51,F8.5)
4449 FORMAT (' ',/'THE RSHTBR VALUE CLOSEST TO RSBRDG IS: ',T51,F8.5)
5555 FORMAT (' ',///'THE ',I4,'(1-',F4.3,') QUANTILE IS:',T49,F8.3)
5556 FORMAT (' ',/'THE VALUE OF RSHAT FOR THAT QUANTILE IS:',T51,F8.5)
5557 FORMAT (' ',/'THE DIFFERENCE(RS - RSHAT) IS:',T51,F8.5)
5656 FORMAT (' ',/'THE VALUE OF RHTSTR FOR THAT QUANTILE IS:',T51,F8.5)
5666 FORMAT (' ',/'THE VALUE OF RSHTBR FOR THAT QUANTILE IS:',T51,F8.5)
5657 FORMAT (' ',/'THE DIFFERENCE(RS - RHTSTR) IS:',T51,F8.5)
5667 FORMAT (' ',/'THE DIFFERENCE(RS - RSHTBR) IS:',T51,F8.5)
5755 FORMAT (' ',///'SINCE THE NO. OF MISSION TESTS IS THE SAME FOR',
      +' ALL COMPONENTS THE CLOSED FORM SERIES SYSTEM RELIABILITY ',
      +' 'RHTSTR' IS COMPUTED')
6666 FORMAT ('+', '*****',
      +'* RUN INPUT SETTINGS FOR ADJUSTED SUM OF THE NI AI *****',
      +'*****')
6667 FORMAT (' ',///'NUMBER OF REPLICATIONS:',T50,I4)
6668 FORMAT (' ',///'NUMBER OF COMPONENTS:',T50,I4)
6669 FORMAT (' ',///'SYSTEM RELIABILITY FUNCTION:',T50,'SERIES')
6699 FORMAT (' ',///'SYSTEM RELIABILITY FUNCTION:',T50,'BRIDGE')
6670 FORMAT (' ',///'MASTER UNRELIABILITY USED:',T50,F8.5)
6770 FORMAT (' ',///'ZERO FAILURE SCALING FACTOR:',T50,F5.2)
6671 FORMAT (' ',///'INPUT WEIGHTS(A SUB I'S):')
6674 FORMAT ('+',///'*****')

```

```

+ '**R U N R E S U L T S*****' ,
+ '*****')
6675 FORMAT ('+',///'*****' ,
+ ' ESTIMATE ERRORS *****' ,
+ '*****')
6676 FORMAT ('+',///'*****' ,
+ ' TRUE CONFIDENCE LIMITS *****' ,
+ '*****')
END

```

APPENDIX D. EXTERNAL SUBROUTINES

These six subroutines are used by all three programs listed in appendices one through three. They must be appended to the particular main program being run or they must be available on the same disk as the one from which the main program is being run.

SUBROUTINE IMAX(SEQ, N, MX, INDEX)

```
***// THIS ROUTINE IDENTIFIES THE MAXIMUM ELEMENT OF AN INTEGER VECTOR
* NOTE THAT SINCE THE TEST IS .GT. SUBROUTINE ONLY PICKS THE FIRST
* OCCURRENCE OF A MAX SUCH AS IN THE CASE OF A TIE.
***// ALSO, ARRAY PASSED MUST BE TYPE INTEGER
REAL*4 MX
INTEGER SEQ(N), N, I, INDEX
MX = 0.
DO 5 I=1, N
    IF(SEQ(I).GT.MX) THEN
        MX = SEQ(I)
        INDEX = I
    ELSE
        END IF
5 CONTINUE
END
```

SUBROUTINE RBRIDG(QI,N,RRSS)

```
***// THIS SUBROUTINE CALCULATES THE "TRUE" RELIABILITY OF A 5-COMPONENT
***// BRIDGE STRUCTURE
REAL*4 QI(N), RRSS
INTEGER N
IF(N.NE.5) THEN
    WRITE(1,('WARNING: BRIDGE STRUCTURE ONLY USES ',
+ 'THE FIRST 5 COMPONENTS'))
ELSE
    END IF
    RRSS=(1-QI(1))*(1-QI(4))+(1-QI(2))*(1-QI(5))+(1-QI(1))*(1-QI(3))*
    C(1-QI(5))+(1-QI(2))*(1-QI(3))*(1-QI(4))-(1-QI(1))*(1-QI(2))*
    C(1-QI(3))*(1-QI(4))-(1-QI(1))*(1-QI(2))*(1-QI(3))*(1-QI(5))-
    C(1-QI(1))*(1-QI(2))*(1-QI(4))*(1-QI(5))-(1-QI(1))*(1-QI(3))*
    C(1-QI(4))*(1-QI(5))-(1-QI(2))*(1-QI(3))*(1-QI(4))*(1-QI(5))+
    C2*(1-QI(1))*(1-QI(2))*(1-QI(3))*(1-QI(4))*(1-QI(5))
END
```

SUBROUTINE RHTBRG(QHTUP,AHT,N,RRBRDG)

```
***// THIS SUBROUTINE CALCULATES THE ESTIMATED RELIABILITY OF A
***// 5-COMPONENT BRIDGE STRUCTURE.(ONLY CARRIED OUT TO THE Q-CUBED TERM
REAL*4 QHTUP, RRBRDG, AHT(N)
INTEGER N
RRBRDG=1-((QHTUP**2)*(AHT(1)*AHT(2)+AHT(4)*AHT(5)))-
C((QHTUP**3)*(AHT(1)*AHT(3)*AHT(5)+AHT(2)*AHT(3)*AHT(4)))+
```

```

C((QHTUP**4)*(AHT(1)*AHT(2)*AHT(3)*AHT(4)+AHT(1)*AHT(2)*AHT(3)*
CAHT(5)+AHT(1)*AHT(2)*AHT(4)*AHT(5)+AHT(1)*AHT(3)*AHT(4)*AHT(5)+
CAHT(2)*AHT(3)*AHT(4)*AHT(5)))-
C2*((QHTUP**5)*(AHT(1)*AHT(2)*AHT(3)*AHT(4)*AHT(5)))
END

```

SUBROUTINE RHTSRS(QHTUP,AAHTI,N,RRSHAT)

```

***// THIS ROUTINE CALCULATES THE VALUE OF THE SYSTEM RELIABILITY OF A
* SERIES SYSTEM OF 'N' NO. OF COMPONENTS WHICH HAVE UNRELIABILITY
***// 'QHTUP'. THE FINAL SYSTEM RELIABILITY VALUE PASSED IS 'RRSHAT'
REAL*4 QHTUP, RRSAT, AAHTI(N)
INTEGER I, N
RRSHAT = 1.
DO 100 I=1, N
    RRSAT = RRSAT * (1 -(AAHTI(I)* QHTUP))
100 CONTINUE
END

```

```

SUBROUTINE RMAX(SEQ, N, MX, INDEX)
***// THIS ROUTINE IDENTIFIES THE MAXIMUM ELEMENT OF A REAL VECTOR
* NOTE THAT SINCE THE TEST IS .GT. SUBROUTINE ONLY PICKS THE FIRST
* OCCURRENCE OF A MAX SUCH AS IN THE CASE OF A TIE.
***// ALSO, ARRAY PASSED MUST BE TYPE REAL
REAL*4 MX, SEQ(N)
INTEGER N, I, INDEX
MX = 0.
DO 5 I=1, N
    IF(SEQ(I).GT.MX) THEN
        MX = SEQ(I)
        INDEX = I
    ELSE
        END IF
5 CONTINUE
END

```

SUBROUTINE RSR(S,QIS,N,RRS)

```

***// THIS ROUTINE CALCULATES THE VALUE OF THE SYSTEM RELIABILITY OF A
* SERIES SYSTEM OF 'n' COMPONENTS WHICH HAVE UNRELIABILITY
***// 'QIS'. THE FINAL SYSTEM RELIABILITY VALUE PASSED IS 'RRS'
REAL*4 QIS(N), RRS
INTEGER I, N
RRS = 1.
DO 100 I=1, N
    RRS = RRS * (1 - QIS(I))
100 CONTINUE
END

```

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